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DIRECT INJECTION STRATIFIED CHARGE ENGINE DEVELOPMENT

Summary Report

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by

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SNC # 6427

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17. Abstract

Significant reductions in fuel consumption can be realized through the use of direct fuel injection internal combustion piston engines operating on the stratified charge principle. The DISC engine technology, developed by Texaco Inc., can be adapted to existing vehicle engines on an original equipment supplier or retrofit basis, and permits the use of a wide range of engine fuels, thereby allowing an increase in overall refinery efficiency. In this study, the means of converting the Ford 300 6-cylinder engine to DISC operation, supplier network, user potential, and preliminary economics were evaluated. Subject to test confirmation of proposed design changes, the engine conversion was found to be potentially viable. The engine could be produced in Canada in retrofit form. A plan for subsequent programs leading to volume manufacture was outlined.

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17. Résumé

L'adoption du moteur à pistons et à combustion interne, equipé d'un système à injection directe et fonctionnant selon le principe de la charge stratifiée, peut permettre d'importantes réductions de la consommation de carburant. La technologie du moteur à injection directe et à charge stratifiée, élaborée par Texaco Inc. peut être adaptée sur les moteurs de véhicules existants, soit par le constructeur d'équipement de première monte, soit en les réadaptant à cette nouvelle technologie, ce qui permet d'utiliser une grande variété de combustibles pour moteur, augmentant ainsi le rendement global des raffineries. Cette étude décrit les moyens de convertir le moteur Ford 300 à 6 cylindres de sorte qu'il puisse fonctionner sur le principe du moteur à injection directe et à charge stratifiée. Le réseau de distribution, les potentialités qu'il recèle pour son utilisateur et l'évaluation économique préliminaire ont été évalués et le concept prouvé rentable. Un plan de programmes ultérieurs de construction à grande échelle a été conçu.

18. Mots-clés	19. Diffusion
Conception des moteurs, moteur à pistons automotive, charge stratifiée, injection directe	Le CDT dispose d'un nombre limité d'exemplaires

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SNC

1.0 FOREWORD

Among the many scenarios anticipated for vehicular highway transport, all but the most extreme anticipate that the conventional internal combustion engine, with appropriate development, will remain a primary power plant through till the end of the present century.

Present engine design trends indicate that increasing emphasis will be placed on fuel saving, energy conservation and reduced exhaust pollutants. A further desirable development would be the capacity for future engines to operate on the wide range of fuels promoted as alternatives or extenders to conventional crude oil derived gasoline.

The Direct Injection Stratified Charge (DISC) engine is an excellent example of such development. In fact, numerous transportation fuel studies indicate that the DISC concept, as applied to contemporary piston engines, will eventually dominate the alternative fuels engine market.

The concept, which has been under development by Texaco Inc. since the early 1950's, utilizes a coordinated arrangement of fuel injection, positive ignition and air swirl within the combustion chamber to yield "patch burning" of a combustible mixture. The resulting ability to burn unthrottled, overall lean fuel/air mixtures produces engines having excellent fuel economy with inherently low emissions of exhaust pollutants. The technology is also compatible with high compression ratios and inlet pressure charging.

Equally important, the unique coordinated arrangement prevents combustion knock without regard to fuel octane rating and ensures smooth ignition without regard to cetane rating. This fuel tolerance capability allows DISC engines to operate on a variety of fuels, including gasoline, diesel fuel, alcohols and broad boiling range (broad-cut) fuels. The latter category of engine fuels is especially interesting, since production of broad-cut fuels allows a refinery to increase the amount of fuel recoverable from a given quantity of crude oil, thereby increasing the available supply of engine fuels.

Further advantages of the DISC engine concept, initially known as the TCP (Texaco Combustion Process) and subsequently as TCCS (Texaco Controlled Combustion System), include the facility of its application to existing engine designs and production line tooling, thereby reducing the long, costly new engine development process. DISC hardware also has the potential to be economically retrofitted to existing vehicles, notably light delivery trucks in fleet service.

It must however be recognized that although the principle is conceptually applicable to any engine - gasoline or diesel - each specific application involves a particular set of constraints, and each engine design has to be evaluated separately on its own merits.

By comparison with diesel engine vehicle installations, the DISC engine is lighter, cheaper, more flexible and just as efficient. In one retrofit comparison (based on actual cost experience by United Parcel Service) the total cost of installation of a DISC engine retrofit kit was identified at US $2,500. The comparable diesel retrofit costs were over US $6,000 and involved changes to the power train and front suspension, in addition. Furthermore the diesel engine offered no relief from spot fuel shortages, whereas the DISC engine can operate on any grade of gasoline, or diesel fuel.

Despite the attractiveness of the DISC concept and the extent of work conducted, there has to date been no widespread application, and virtually no work done in Canada. The reasons have varied during the evolution to the present advanced status of the pertinent technology. Initially (1950's, 1960's) the engine market emphasis was for increased power followed by concern for pollution control, and then a concerted industry effort with respect to vehicle safety. The "energy crisis" has seen a diffused industry effort covering a wide spectrum of activities with a general trend to vehicle down-sizing in response to market demand. However, Texaco Inc. and United Parcel Service (UPS) are currently conducting a prototype DISC engine evaluation program based on the General Motors 292 cubic inch engine installed in UPS delivery vans. Test results to date are encouraging, with fuel economy being improved by approximately 30% under city driving conditions.

The SNC Group has followed the evolution of the work done by Texaco, with this interest resulting in the submission of a proposal by SNC to the Government of Canada for a study in several phases of the DISC concept applied to a suitable engine having Canadian production potential.

After careful consideration, the Ford 300 cu. in. 6 cyl. engine, currently installed in the Ford Econoline Van and Pickup, was selected for study. This engine was chosen as a unit in widespread use with a 15-year history of reliable service, and which, with current production of 50,000 units/year and growing, promises to make it the most popular gasoline truck engine in Canada. U.S. experience, proportionally greater, parallels Canadian trends. It derives from a family of engines and a design philosophy for robustness which portend operation without problems at the relatively high compression ratio which the DISC application would involve.

This Phase 1 report details the results of a study to define the technical and economic feasibility of a stratified charge engine package applicable to the selected Ford engine.

The overall project has been planned to follow this initial study by sequential phases comprising detail design, bench testing, fleet installation and evaluation, followed by eventual production implementation.

SNC Inc. provided overall project management and coordination, and economic evaluation; Texaco Inc. provided the basic technology; Ontario Research Foundation participated in the design work and will perform development testing of prototype engines and components. Purolator Courier Ltd. will actively participate in establishing performance requirements for the modified engine and will provide services for fleet evaluation of the finished product.

Throughout the body of this report the f.p.s. system of units has been used in preference to metric units, consistent with continuing practice in the North American engine component parts industry.

2.0 OVERALL PROGRAM

The overall engine program consists of four phases:

Phase 1 Preliminary feasibility study and program planning
Phase 2 Prototype engine design, build and bench testing
Phase 3 Fleet installation and evaluation
Phase 4 Production implementation

An integral part of the program is the evaluation of engine performance on a selection of petroleum - based fuels and evaluation of operation on methanol.

Concurrent with the prototype engine engineering program, economic and marketing studies have been planned to culminate in the negotiation of manufacturing and marketing agreements leading to product sales.

Phase 1 (covered by this report)

The principal activities of this phase were performed to ensure that the anticipated modifications to the Ford 300 engine were theoretically sound, to determine overall project economics, and to determine the development program necessary to achieve a technically and economically viable end product.

Given this foregoing design investigation it would be possible to prepare a development plan with estimated costs and schedule for the later phases.

The specific Phase 1 activities are given in following sections of this report.

Phase 2

Phase 2 includes preparation of manufacturing drawings, production of parts and construction of engines for bench testing, evaluation, and modification as necessary, and testing of the evolved design to determine fuel consumption, emissions, retrofit and service constraints, and to obtain initial wear estimates. Prototype service tests will be conducted. Identification of parts suppliers and a fleet evaluation plan will be developed concurrently.

This phase will include a preliminary market study and an economic analysis based on the prototype engine's measured performance and estimated production cost. Potential contractors and licencees will be identified during this phase of the program.

Phase 3

Phase 3 will cover a fleet installation of typically 20 vehicles operating over a full calendar year. These vehicles will be monitored together with a control group to compare fuel economy, service and maintenance requirements, and operating economics. In parallel with the fleet evaluation a production evaluation will be undertaken to finalize component and assembly costs.

A full market study will be completed, resulting in the development of a marketing strategy as a prelude to negotiating marketing agreements.

This phase will be completed by an evaluation report covering all work done including an updated economic analysis.

Phase 4

Phase 4 will include the initiation of engine manufacture and market introduction.

3.0 FEASIBILITY STUDY

3.1 General

The study was conducted in accordance with a SPEC planning network developed at the contract outset as a set of inter-related activities. These comprised classification of the TCCS principle, determination of the vehicle (and hence engine) performance requirements, application of the technology to the Ford 300 cu.in. displacement engine, and translation of this information into assembly and component specifications of sufficient depth that the preliminary economics and methodology for future work could be ascertained.

Key elements of the technology transfer activity included the involvement of the pertinent agencies in all steps of the technology application and implementation process.

3.2 Study Team

The participants in this study included SNC Inc., as prime contractor, Ford Motor Company, Texaco Inc., Ontario Research Foundation (ORF), and Purolator Courier Ltd.

4.0 TECHNICAL FEASIBILITY

4.1 Texaco Controlled Combustion System (TCCS) Principle

The basic concept of the TCCS allows initiation of combustion and control of its progress in the combustion chamber so that efficient energy conversion can be accomplished without the requirement for high octane or cetane fuel ratings.

Octane rating is an empirical engine test method that evaluates a gasoline's resistance to spontaneous ignition or "knock". Cetane is based on a different engine test, which determines a diesel fuel's ease of spontaneous ignition. High cetane number enhances cold starting and permits high-speed diesel engine operation.

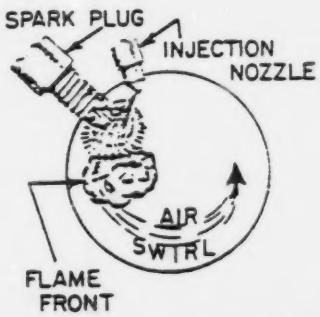
Utilizing a conventional piston-type engine with poppet valves located in the cylinder head, the Texaco process dictates that fuel shall be directly injected into the engine cylinder, mixed with air and ignited at the correct time to ensure efficient combustion.

The incoming charge is so directed during the intake stroke that it rotates (or "swirls") upon entering the cylinder. The air charge continues to spin during the compression stroke, at the end of which the air is forced into a small cup in the top of the piston. Entry into the cup causes the air rotational rate to increase, i.e. the angular momentum is conserved.

Fig. 1 illustrates the stages of combustion taking place in the piston cup. These simplified plan views of the combustion chamber show the coordinated arrangement of air swirl, high pressure fuel injection, and positive ignition. When combustion is to begin, near the end of the compression stroke, injection of the fuel into the swirling air is started and the mixture formed is ignited to establish a stationary flame front downstream from the fuel injection nozzle. As injection continues, additional mixture is formed and supplied to the flame front to be consumed at the rate at which it is formed.

Many characteristics of the DISC engine are direct consequences of the above concept. Initiating injection near the time for ignition eliminates the possibility of pre-ignition (knock) regardless of the octane number of the fuel. The positive ignition feature eliminates any need for a fuel cetane number or the high compression ratio associated with the diesel engine. Also, it is evident that load control can be achieved by control of fuel quantity only, without the use of inlet air throttling. DISC engines thereby exhibit the good fuel economy of lean mixture engines.

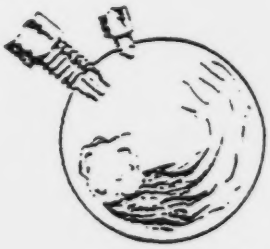
Fig. 1 **The Texaco Controlled Combustion System (TCCS)**



Air swirl, created by the intake port during the intake stroke, is intensified in a cupped piston design during the compression stroke. Combustion, initiated by fuel injection and positive spark ignition, establishes a flame front immediately downstream from the injection nozzle.

Spark continues; fuel is injected at a controlled rate; air continues to be supplied by the swirl to mix with fuel. The flame front is established and cylinder pressure builds at a controlled rate.

Spark is discontinued; fuel injection continues to mix fuel with air supplied by the swirl to feed the flame front.



Fuel injection is discontinued; flame front fades in intensity, but combustion continues until all fuel is consumed. The result is a clean burn of fuel in a lean mixture yielding low exhaust emissions.

The presence of the air swirl in the combustion chamber is one of the basic requirements for successful operation of the system, with the rate of swirl directly influencing the combustion duration and thereby the efficiency of the engine.

Experience has shown that although indicated thermal efficiency rises with increasing compression ratio, in reality the marginal improvements are small for ratios beyond approximately 12:1, as mechanical friction and other losses rise.

Extensive theoretical and practical work has established the optimum size and proportions of the cup for any particular operation. The cup has been idealized as having parallel sidewalls and a flat bottom, but this profile is by no means a constraining factor.

4.2 Engine Specific Factors

Application of the DISC principle to a specific engine design involves:

- Modification of the cylinder head to accommodate the required inlet port geometry, the fuel injection nozzle and relocated spark plug.
- Provision of the pertinent fuel injection system.
- Provision of the pertinent ignition device with appropriate timing.
- Modification of the pistons to accommodate the required cup profile.
- Modification of pertinent engine parts, as necessary, to accept the head, fuel injection system, ignition system, valve train and piston changes.

Thus each engine design involves its own set of modifications, and no single design solution exists that is applicable to more than one engine.

4.3 Application of the DISC Principle to the Ford 300 Engine

The fundamental application of DISC technology to the engine was undertaken by Texaco Inc. to determine the basic design modification parameters. Thus for the 4.00" bore and 3.98" stroke of the Ford engine the location and form of inlet and exhaust ports, location of the spark plug, and location and orientation of the fuel injector were determined. Similarly, the shape of the piston crown profile and also the valve timing were determined by Texaco. The design evolved was based on a combination of theoretical studies and interpolation of existing empirical data derived from previous tests on a wide range of engine and component configurations.

These studies determined the changes that would be required to the existing cylinder head form to accommodate the revised inlet port geometry, relocated spark plug, fuel injector nozzle, revised combustion chamber profile and revised valve location. It was ascertained during the study that all of these geometric changes could be affected without necessitating changes to the engine block or head attachment bolts, with the exception of the push rod openings.

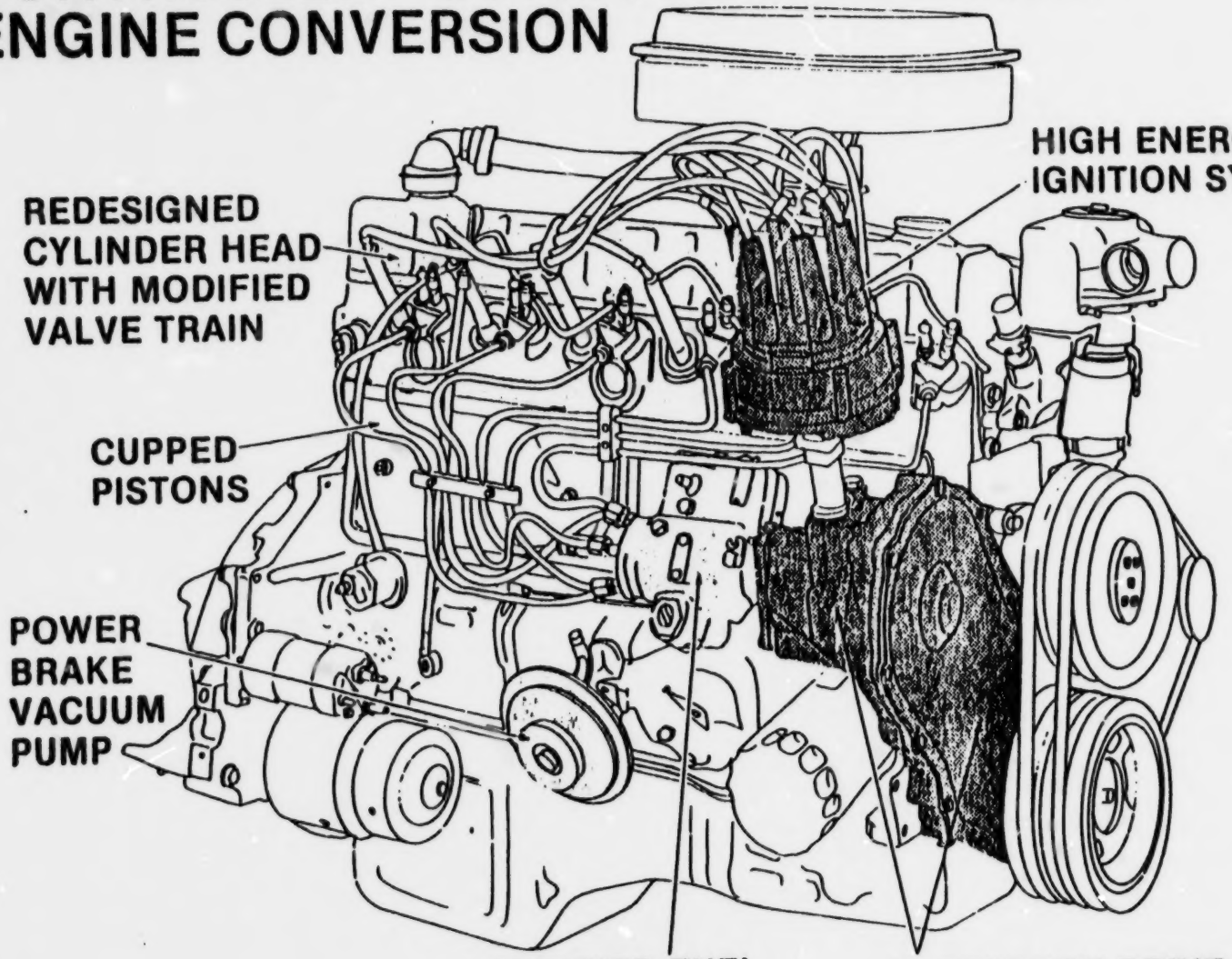
Study of the valving determined that the valve push rods would have to be realigned such that a potential interference would exist at the upper level of the block. This could be overcome by a single broaching operation of the block to enlarge the twelve push rod openings. The utilization of ball stud rockers to circumvent this rework was evaluated, but was discarded due to geometric complications. The required modification of the valve timing would be achieved by a simple replacement of the camshaft.

Replacement of the current carburetion system by a fuel injection system requires an additional timing drive, fuel pump and injection nozzles.

Maintenance of the spark throughout the duration of the fuel ignition pulse places more strigent requirements on the ignition system. Thus a new high energy ignition system is also required, being physically larger than the stock ignition system. These elements are shown in Fig. 2.

The engine bay of an Econoline van was checked for dimensions (see "Engine Compartment Dimensions" drawing) and it was determined that no packaging problems existed for the introduction of these items.

CONTROLLED-COMBUSTION SYSTEM ENGINE CONVERSION



SNC

Fig. 2

Examination of the requirements for re-profiling of the piston crown, however, revealed a 'classic' engine design evolution problem, i.e. limited engine block height. The concept of cylinder charge high swirl angular velocity at piston top-dead-centre implies introduction of a cup having a specific shape in the piston crown. From a structural point of view, since the piston crown thickness and crown underside-to-wrist pin outside diameter distances are already close to minima, the required change in piston profile could only be achieved by raising the height of the piston crown outer annulus relative to the wrist pin centre-line, causing the piston crown to extend above the deck of the block at top-dead-centre. In the present instance the protrusion was 0.375".

Eight direct design solutions were evaluated to overcome this situation:

1. Counter-bored cylinder head
2. Counter-bored cylinder head with "stepped" piston
3. Cylinder head and piston with matching crown bevel
4. Shortened connecting rod
5. Cylinder block sleeved to reduce bore diameter
6. Reduced displacement cup
7. Modified piston cup profile
8. Redesign of the crankshaft

Of these possibilities only solutions 7 and 8 were technically and economically viable. The modified cup profile would involve more unknown variables and hence greater development work and risk. A new crankshaft would involve known quantities during development but would lead to a higher end product cost. A logical development plan would pursue both solutions, with the new crankshaft in the contingency role.

As a result of these studies of engine fundamental geometries, a preliminary engine design was developed to serve as the basis for further work. The engine description, new production items required, tooling required and vehicle requirements are given in Tables 1 - 4 inclusive.

TABLE 1 ENGINE BASIC DESIGN PARAMETERS

Cylinder pressure	1000 psi (max.)
Cylinder pressure rise rate	60 psi per crankangle degree
Engine speed	3000 RPM (max.)
Compression ratio	12.0 (approx.)
Ratio of cylinder bore to piston cup diameter	2.0 (min.)
Ratio of connecting rod length to crankshaft throw radius(L/R)	3.1 approx. (min.)
Piston pin diameter	0.97" (min.) per stock Ford 300 engine
Protrusion of piston pin from bottom of cylinder bore at BDC	Pin diameter x 0.25 (max.)
Wall thickness of flat base piston cup	0.25" (min.)
Ignition system Requirements	Timing triggered by fuel injector nozzles.
	Continuous spark, duration 20 - 40 degrees crankshaft travel.
	Radio frequency interference to be minimized.
Fuel System Requirements	Operation on gasoline, diesel oil and two intermediate broad-cut fuels.
	Operation on methanol and ethanol with system modifications (to be defined).

TABLE 2 NEW PRODUCTION ITEMS REQUIRED FOR DISC RETROFIT KIT

Qty	Description	Tooling Req'd (T) or Stock item (S)	Material Category
1	Crankshaft	T	forged steel
6	Connecting rods	T	forged steel
6	Pistons	T	forged aluminum
6 sets	Piston rings	S	cast steel
1	Cylinder head	T	cast iron
2	Exhaust manifolds	T	cast iron
2	Intake manifolds	T	cast iron
1	Camshaft	T	cast iron
1	Valve cover	T	cast aluminum
1	Injection pump drive housing	T	cast aluminum
1 set	Misc. brackets and cover plates	T, S	stamped steel
1	Ignition system	S	-
1	Valve train	S	-
1	Vacuum pump	S	-
1	Fuel injection system incl. pump drive	S, T	-
1 set	Air and fuel filters incl. housing	S	-
1	Thermostat and cooling system modifications	S, T	-
1 set	Gaskets	S	-

TABLE 3 MAJOR TOOLING REQUIRED (exclusive of machining fixtures)

Item	Tooling	Prototype	Production
Pistons (forging)	Forging dies	X	X
Crankshaft (forging)	Hammer dies Restrike dies Trimmer dies Twister dies		X
Connecting rods (forging)	Hammer dies Trimmer dies Coining dies		X
Brackets Cover plates (stamping)	Stamping dies		X
Cylinder head (casting)	Cope and drag patterns Various coreboxes	X	X
Intake manifold	Cope and drag patterns		X
Exhaust manifold	Coreboxes		X
Valve cover			X
Injection pump drive housing			X
Camshaft			X
Thermostat housing			X

TABLE 4 VEHICLE REQUIREMENTS

The following vehicle requirements were developed in consultation with Purolator Courier Ltd., fleet operators of Econoline delivery vans, based on their experience with the Ford 300 engine:

Test Vehicle	Ford Econoline Van
Vehicle GVW, max.	7000 lb.
Peak payload	1800 lb.
Driving cycle, Eastern Canada mileage	35% urban 65% highway
HP required, approx.	100
RPM, max.	3000
Transmission type	Automatic, 3-speed
Cold start temperature, min.	-20°F
Engine oil and filter change interval	8000 mi.
Engine minor tuneup interval	16,000 mi.
Engine overhaul interval	120,000 mi.

5.0 MARKET ASSESSMENT AND ECONOMIC FEASIBILITY

5.1 User Potential

In vehicle service, the DISC engine would gain the greatest market acceptance in the domain of light truck low-speed (urban) operation, because of the predominance of contemporary light vehicles using spark-ignited engines operating on gasoline (and lately, propane). These engines suffer great pumping losses due to inlet throttling, resulting from their high idling times and mainly low vehicle speed operation. The DISC engine is better suited to this type of vehicle market, for a variety of reasons outlined earlier in this report, and has a particular advantage over diesel powerplants in terms of ease of vehicle retrofit conversion.

5.2 Retrofit Potential

The possibility of convenient DISC retrofit is the subject of great interest on the part of light truck fleet operators, judging by the number of inquiries received by Texaco in the Unites States from major fleet users.

A brief survey of DISC potential among fleet users of delivery vans in Canada conducted as part of this study produced a parallel positive response. An important finding of this survey is the fact that big delivery fleet operators tend to rebuild engines several times at intervals ranging from 80,000 to 120,000 miles over the life of the vehicle, making them ideal candidates for retrofitting DISC engines in large numbers.

Major fleet users in Canada of the Ford 300 engine include twenty-two firms, of which five were contacted as a representative sample and interviewed during this study. These firms were surveyed not only for their own experience but also their knowledge of general industry practices. Assumptions stated in this section were based upon survey data.

The retrofit potential overall market size for Canadian trucks having Ford 300 engines has been estimated for each calendar year until 1986, with the results illustrated in Fig. 3. Average annual retrofit potential in Canada is approximately 15,000 vehicles, assuming that the average vehicle life is 7 years and that 50% of the vehicles' engines are rebuilt after 4 years of service. The United States potential (Fig. 4), also based on historical sales figures, is 10 times greater at 150,000 vehicles per year, with average fleet size being larger than the Canadian counterpart.

5.3 Original Equipment Sales Potential

Data supplied by Ford has been used to prepare Fig. 5, which shows the relationship between potential market share and price premium for light truck original equipment options offering a range of fuel mileage improvements over a suburban (mixed) driving cycle. It should be noted that the data applies to the price sensitive market only, excluding those buyers who buy on the lowest first cost basis regardless of operating costs. So also no credit has been allocated for secondary benefits such as reduced maintenance, better cold weather performance, or multifuel capability.

For operation on gasoline, Fig. 5 indicates that a small segment of the original equipment light truck market could be captured based on the projected cost premium of US $2000 to US $3000 for a DISC engine. The increased fuel mileage when operating on diesel or other broad-based fuels would allow a much greater market penetration, to the extent that such a DISC engine package would sucessfully compete with original equipment diesel and propane engine installations for their respective market shares.

Fig. 3 CANADA MARKET RETROFIT POTENTIAL
FORD 6 CYL. TRUCKS

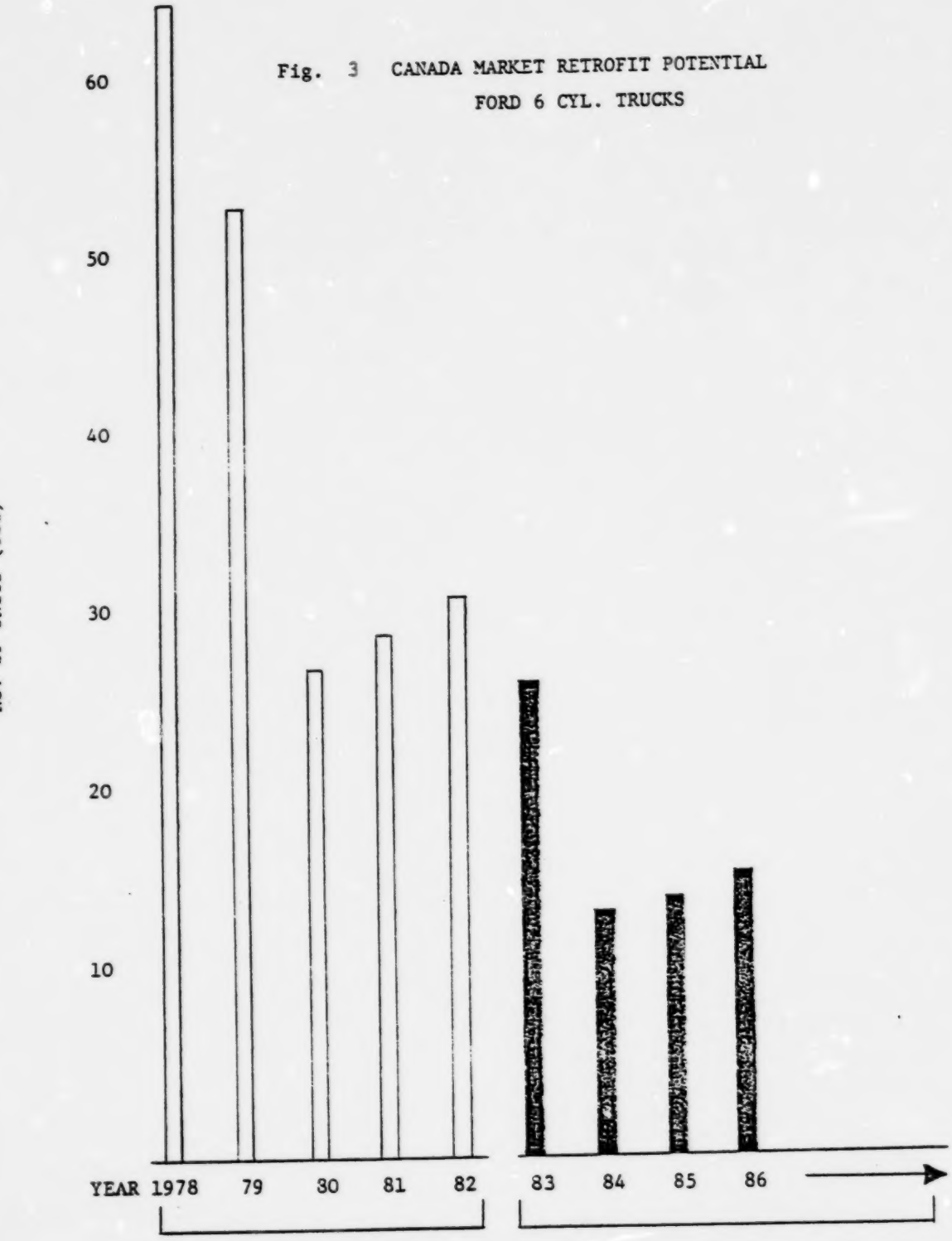


Fig. 4 U.S.A. MARKET RETROFIT POTENTIAL
FORD 6 CYL. TRUCKS

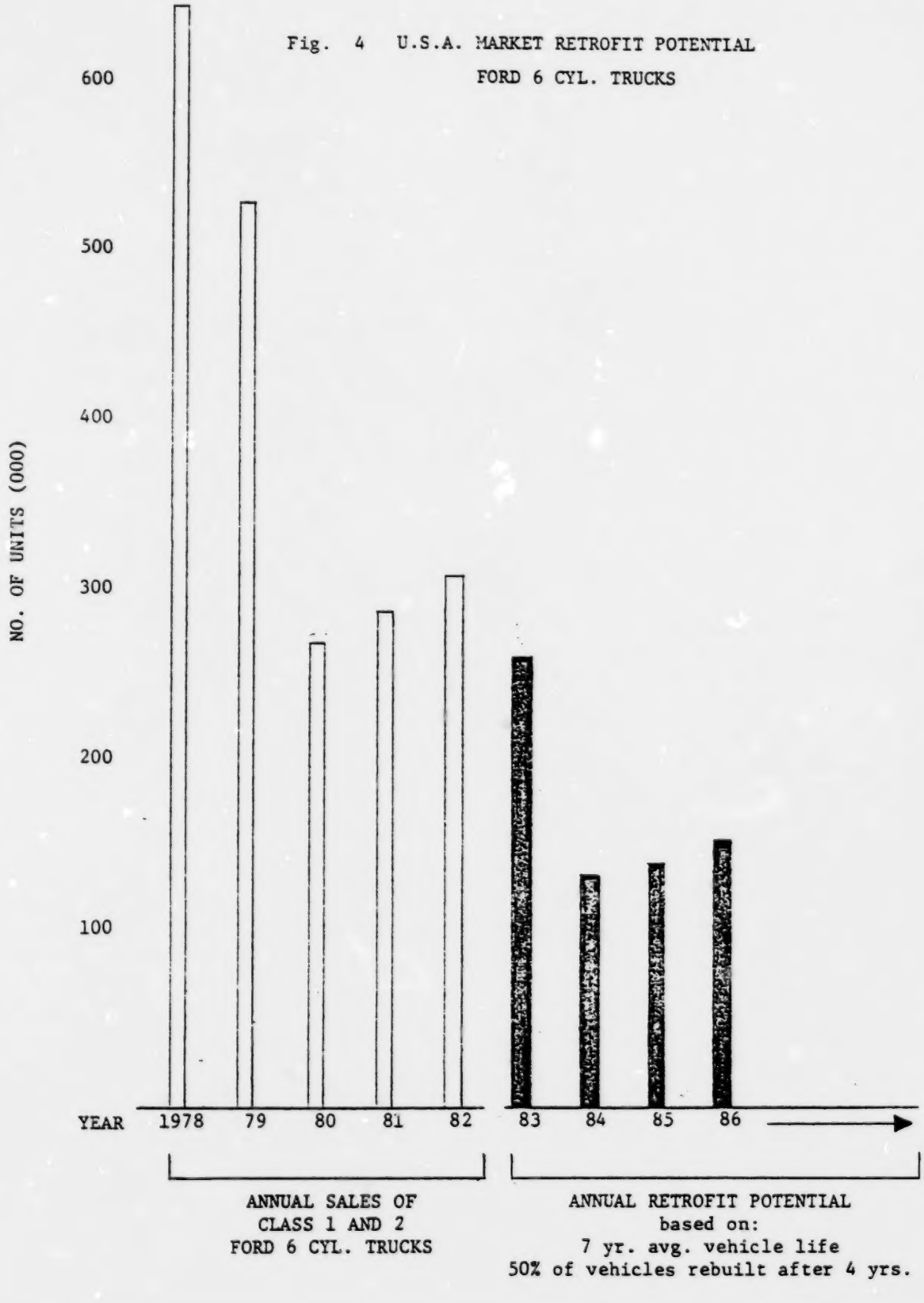
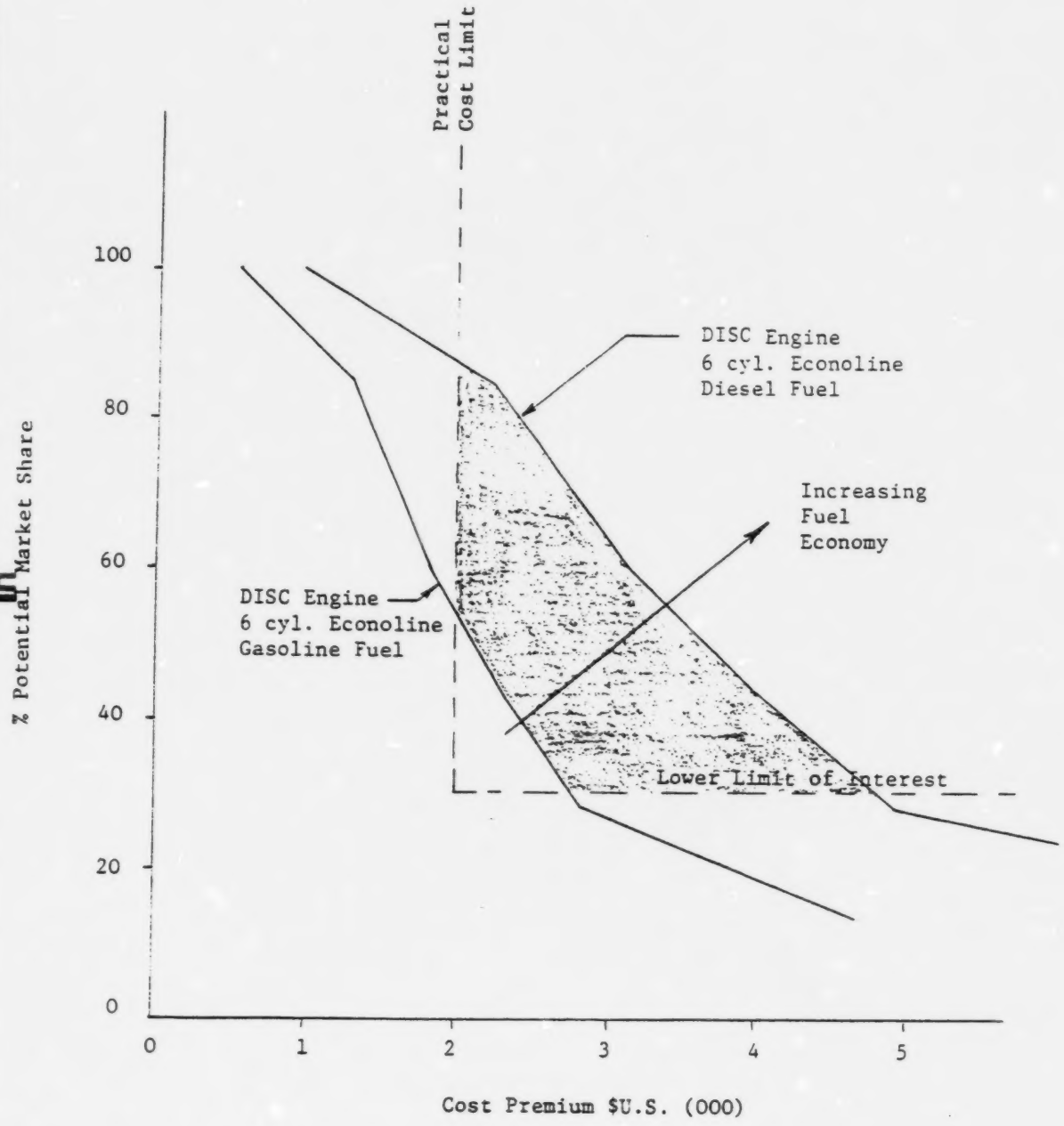


Fig. 5 MARKET SHARE vs COST PREMIUM



Based on: - price sensitive market segment
- 2 yr. payback period
- mixed driving cycle (60% urban)
(40% highway mileage)

6.0 CONCLUSIONS AND RECOMMENDATIONS

6.1

The Direct Injection Stratified Charge engine technology developed by Texaco Ltd. has been examined and its application to the Ford 300 c.i.d. 6 cylinder engine was found to be technically feasible.

6.2

The economics and market aspects of an appropriate engine commercialisation program have been evaluated and were found to be viable. A Canadian Original Equipment Manufacturer will have to be identified prior to implementation of such a program.

6.3

A development program using Canadian resources has been identified to achieve an advanced engine design with minimum risk. This development program should be pursued to the prototype engine stage to ensure a DISC engine development capability in the context of a "contingency technology" available to Canadians.

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par

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Le contenu de ce rapport reflète le point de vue de l'entrepreneur et pas nécessairement le point de vue ou la politique du Centre de développement des transports de Transports Canada.

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17. Résumé

L'adoption du moteur à pistons et à combustion interne, equipé d'un système à injection directe et fonctionnant selon le principe de la charge stratifiée, peut permettre d'importantes réductions de la consommation de carburant. La technologie du moteur à injection directe et à charge stratifiée, élaborée par Texaco Inc. peut être adaptée sur les moteurs de véhicules existants, soit par le constructeur d'équipement de première monte, soit en les réadaptant à cette nouvelle technologie, ce qui permet d'utiliser une grande variété de combustibles pour moteur, augmentant ainsi le rendement global des raffineries. Cette étude décrit les moyens de convertir le moteur Ford 300 à 6 cylindres de sorte qu'il puisse fonctionner sur le principe du moteur à injection directe et à charge stratifiée. Le réseau de distribution, les potentialités qu'il recèle pour son utilisateur et l'évaluation économique préliminaire ont été évalués et le concept prouvé rentable. Un plan de programmes ultérieurs de construction à grande échelle a été conçu.

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17. Abstract

Significant reductions in fuel consumption can be realized through the use of direct fuel injection internal combustion piston engines operating on the stratified charge principle. The DISC engine technology, developed by Texaco Inc., can be adapted to existing vehicle engines on an original equipment supplier or retrofit basis, and permits the use of a wide range of engine fuels, thereby allowing an increase in overall refinery efficiency. In this study, the means of converting the Ford 300 6-cylinder engine to DISC operation, supplier network, user potential, and preliminary economics were evaluated. Subject to test confirmation of proposed design changes, the engine conversion was found to be potentially viable. The engine could be produced in Canada in retrofit form. A plan for subsequent programs leading to volume manufacture was outlined.

18. Key Words	19. Distribution Statement
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1.0 AVANT PROPOS

Si on se réfère aux scénarios anticipant sur l'évolution du transport routier, on constate que les experts sont unanimes à envisager que le moteur conventionnel à combusion interne, avec une mise au point appropriée, restera la principale source motrice jusqu'à la fin de ce siècle. Dans le domaine de la conception des moteurs, les tendances actuelles indiquent que, de plus en plus, l'accent sera mis sur l'économie des combustibles, la conservation d'énergie et la réduction des polluants provenant des émissions de gaz des véhicules. L'autre pas qu'il serait souhaitable de franchir consisterait à rendre les futurs moteurs capables de fonctionner avec une large gamme de combustibles avantageusement présentés comme substituts ou extendeurs de l'essence ordinaire dérivée du pétrole brut.

Le moteur à injection directe et à charge stratifiée est un excellent exemple d'une telle entreprise. En fait, de nombreuses études relatives au carburant utilisé dans le transport indiquent que le concept du moteur à injection directe et à charge stratifiée, appliqué aux actuels moteurs à pistons, finira par dominer sur le marché des moteurs consommant des carburants de substitution.

Le concept sur lequel Texaco Inc. travaille depuis le début des années 50 repose sur une combinaison de l'injection du carburant, l'allumage positif et le tourbillon d'air dans la chambre de combustion visant à produire une combustion localisée du mélange de combustibles. La possibilité qui en résulte et consistant à brûler sans entrave toute le mélange de carburant pauvre et d'air, donne des moteurs capables de réaliser une excellente économie de carburant; il s'y ajoute un avantage inhérent à ce système: une faible émission de polluants. La technologie est aussi compatible avec des taux de compression élevés ainsi qu'avec la turbocompression.

Tout aussi importante est la mise au point unique en son genre qui empêche toute détonation prématurée quel que soit l'indice d'octane et permet un allumage en douceur quel que soit l'indice de cétane. Cette capacité de tolérance vis-à-vis des carburants permet au moteur à injection directe et à charge stratifiée de fonctionner avec des carburants divers dont l'essence, le diesel, l'alcool et les fractions du pétrole possédant les points d'ébullition entre 100°F et 650°F ("broad cut"). Cette dernière catégorie de carburants de moteur est particulièrement intéressante puisque la production de ses combustibles permet aux raffineries d'augmenter la quantité de combustibles récupérables d'une certaine quantité de pétrole brut, accroissant ainsi la réserve de carburants de moteur disponible.

Parmi les autres avantages du principe du moteur à injection directe et à charge stratifiée, d'abord connu sous l'appellation PCT (Procédé de combustion de Texaco) puis sous celle de SCCT (Système de combustion contrôllée de Texaco), il y a sa facilité d'adaptation aux moteurs et aux chaînes d'outillage actuels, ce qui réduit le long et coûteux procès de production des nouveaux moteurs. L'équipement du moteur à injection directe et à charge stratifiée peut s'avérer économique vue qu'il peut convenir aux véhicules existants, notamment les camions légers des flottes de livraison.

Il faut cependant reconnaître que bien que le principe puisse théoriquement s'appliquer à tout moteur - à essence ou à diesel - chaque application spécifique implique un certain nombre de contraintes et il faudrait évaluer les conceptions des moteurs selon leurs mérites respectifs.

Par rapport au montage d'un véhicule à moteur diesel, le moteur à injection directe et à charge stratifiée est plus léger, meilleur marché, plus flexible et tout aussi efficace. En ce qui concerne le retrofit (considéré du point de vue de son coût réel appliqué par United Parcel Service) le coût total de l'installation du retrofit kit a été estimé à 2,500 dollars U.S. Celui du moteur diesel dépassait 6,000 dollars U.S. impliquait en plus des modifications du power train et celles des suspensions avant. En outre, le moteur diesel n'offrait aucunes ressources en cas de panne inopinée de carburant tandis que le moteur à injection direct et à charge stratifiée peut fonctionner quelque soit le niveau de l'essence ou de diesel.

Malgré l'attrait exercé par le concept du moteur à injection directe et à charge stratifiée et l'étendue des travaux menés, il n'y a pas eu à ce jour une application tout aussi importante et en fait aucun travail n'a été mené au Canada dans ce sens. Les raisons à cela ont varié durant l'évolution qui a abouti à l'état avancé de la technologie appropriée. Au début (années cinquante et soixante) l'accent était, sur le marché du moteur, mis sur l'augmentation de la puissance puis sur le contrôle de la pollution et ensuite sur un effort concerté allant dans le sens de la sécurité des véhicules. La crise de l'énergie est allé de pair avec un effort industriel inarticulé couvrant un vaste spectre d'activités avec une tendance générale visant à réduire les dimensions des véhicules afin de satisfaire les demandes du marché. Cependant, Texaco Inc et United Parcel sont en train d'exécuter un programme d'évaluation du prototype du moteur à injection directe et à charge stratifiée basée sur le moteur à 292 p.c. de General Motors monté sur les fourgons de livraison de U.P.S. A ce jour, les résultats des essais sont encourageants avec une économie de carburant qui s'est améliorée presque d'environ 30% en zone urbaine.

Le Groupe SNC a suivi l'évolution du travail fait par Texaco et cet intérêt a abouti à une proposition qu'il a soumise au Gouvernement du Canada et visant à étudier plusieurs phases de l'application du concept de moteur à injection directe et à charge stratifiée sur un moteur approprié et rentable pour le Canada.

Après sérieuse réflexion, le moteur Ford à 6 cyl. de 300 p.c. actuellement monté sur l'Econoline Van et le Pickup de Ford fut choisi pour étude. Ce moteur a été choisi pour son usage répandu et ses quinze ans de fiabilité et aussi parce que sa production annuelle actuelle équivalant à 50,000 véhicules promet d'en faire le moteur de camion à essence le plus populaire du Canada. L'expérience américaine qui, toutes proportions gardées, est plus importante, évolue parallèlement aux tendances canadiennes. Ce moteur tient d'une famille de moteurs et d'une philosophie de conception caractérisées par la robustesse qui présage d'un fonctionnement sans problèmes à des taux de compression relativement élevés qu'impliquerait l'utilisation du moteur à injection directe et à charge stratifiée.

Ce rapport relatif à la phase 1 détaille les résultats d'une étude définissant la faisabilité technique et économique de la conversion du moteur à injection directe et à charge stratifiée appliqué au moteur Ford choisi.

SNC

L'ensemble du projet a été conçu conformément à cette étude initiale avec les phases successives comprenant l'étude des détails, le banc d'essai, la constitution de flotte et l'évaluation qui pourraient suivies d'une phase de de production.

SNC Inc, a assuré la gestion de projet, la coordination et l'évaluation économique, Texaco Inc à fourni la techologie de base, Ontario Research Foundation a participé au travail d'étude et assurera l'essai de développement des moteurs prototypes et leurs composantes. Purolator Courier Ltée participera activement à la définition des spécifications de performance du moteur modifié et assurera l'évaluation de la flotte des véhicules équippés de ces nouveaux moteurs.

Dans ce rapport, le système impérial a été préféré aux unités métriques conformément à la pratique toujours en vigueur dans l'industrie automobile nord-américaine des pièces de rechange.

2.0 PROGRAMME GLOBAL

L'ensemble du programme de la production du moteur consiste en quatre phases:

Phase 1 Étude préliminaire de faisabilité et ordonnancement
Phase 2 Conception du prototype, construction et essai
Phase 3 Constitution de la flotte et évaluation
Phase 4 Production

L'évaluation de la performance du moteur brûlant des carburants dérivés du pétrole ou du méthanol fait partie intégrante du programme.

Parallèlement à celui qui a trait à l'ingénierie du prototype, les études économiques et l'étude du marché ont été ordonnancées et ont abouti à la négociation de construction et de commercialisation devant mener à la vente.

Phase 1 (couvert par ce rapport)

Les principales activités de cette phase visaient à s'assurer que les modifications prévues sur le moteur de la Ford 300 étaient théoriquement bonnes, à déterminer les aspects économiques du projet global et à définir le programme d'exploitation nécessaire à la réalisation d'un produit fini techniquement et économiquement viable.

Avec cette précédente recherche en matière de conception il serait possible de préparer un plan d'exploitation avec l'estimation des coûts et un plan des phases suivantes.

Les activités spécifiques de la phase 1 figurent dans des sections suivantes de ce rapport.

Phase 2

La phase 2 comprend la préparation des dessins de construction, la production des pièces et la construction des moteurs pour le banc d'essai, l'évaluation et les modifications nécessaires du moteur prototype, et les essais qui en a résulte afin de déterminer la consommation de carburant, les gaz d'échappement, les contraintes de la conversion et de service et d'obtenir les premières estimations en matière d'usure. Les essais de mise en service du prototype seront menés. L'identification des fournisseurs de pièces et un plan d'évaluation de la flotte seront réalisés conjointement.

Cette phase comprendra une étude préliminaire de marché et une analyse économique basée sur la performance et le coût estimé de la production du prototype. Les entrepreneurs et concessionnaires potentiels seront identifiés dans cette phase du programme.

Phase 3

La phase 3 traite de la constitution d'une flotte de 20 véhicules qui ont ceci de particulier qu'ils fonctionneront durant toute une année civile. Un groupe assurera le contrôle de ces véhicules et son rôle consistera à comparer l'économie en carburant, les exigences de service et d'entretien, les aspects économiques de la production. Parallèlement à l'évaluation de la flotte, il sera entrepris une évaluation de la production afin de finaliser les coûts des pièces détachées et ceux de l'assemblage.

Une étude complète du marché sera menée à partir d'une stratégie de marketing, prélude à une négociation d'accords en matière de marketing.

Un rapport d'évaluation couvrant tous les travaux dont une analyse économique réactualisée complétera cette phase.

Phase 4

La phase 4 comportera la mise en service de la construction du moteur et son introduction dans le marché.

3.0 ÉTUDE DE FAISABILITÉ

3.1 Généralités

L'étude a été menée conformément à un réseau de planification conçu en début de contrat comme un ensemble d'activités liées les unes aux autres. Ces dernières comprenaient la classification du principe SCCT, la détermination des exigences de performances du véhicule (et par voie de conséquence celles du moteur), l'application de la technologie au moteur de la Ford à cylindre 300 p.c. et la traduction de cette information et spécifications d'assemblage et de pièces détachées serait si exhaustive que les aspects économiques préliminaires et la la méthodologie des travaux à venir seraient vérifiables.

Les éléments clefs des activités relatives au transfert de technologie englobent la participation des organismes concernés à toutes les phases de la mise en application de cette technologie.

3.2 Groupe d'étude

Les participants à cette étude comprennent SNC Ltée (contracteur principal), Ford Motor Company, Texaco Inc., Ontario Research Foundation (ORF), et Purolator Courier Ltée.

4.0 ÉTUDE DE FAISABILITÉ TECHNIQUE

4.1 Le principe du système de combustion contrôllée de Texaco (SCCT)

Le principe de base du SCCT permet une mise en flamme ainsi qu'une régularisation de sa progression grâce auxquelles s'accomplit une conversion en énergie efficace sans qu'il ne soit nécessaire d'obtenir des taux élevés de l'indice d'octane ou de cétane.

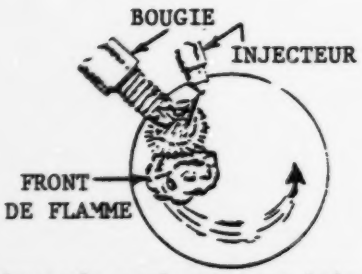
L'indice d'octane est un moyen empirique de tester un moteur et mesure la résistance de l'essence à l'allumage spontané ou "détonation". Celui du cétane est utilisé sur un autre type d'essai déterminant la facilité d'allumage spontané du diesel. L'indice élevé de cétane améliore le démarrage en temps froid et permet au moteur diesel de fonctionner à grande vitesse.

Avec un moteur à piston conventionnel et à soupapes champignons placées dans la culasse, le procédé de Texaco exige que le carburant soit directement injecté dans le cylindre du moteur, mélangé avec de l'air et allumé au bon moment afin d'assurer une bonne combustion.

Durant la course d'admission, la charge est dirigée de sorte qu'elle tourne (ou tourbillonne) en entrant dans le cylindre. L'air continue de tournoyer durant la course de compression à la fin de laquelle il est poussé à l'intérieur d'une petite cuvette située au dessus du piston. L'entrée dans cette cuvette augmente la vitesse de rotation de l'air, c'est-à-dire que le moment cinétique reste le même.

La figure 1 illustre les phases de la combustion qui se produit dans la cuvette du piston. Ces vues en plan simplifiées de la chambre de combustion montrent la combinaison du tourbillonnement de l'air, l'injection de carburant à haute pression et l'allumage positif. Lorsque la combustion est sur le point de se faire et ce vers la fin de la course de compression, commence l'injection du carburant dans l'air tourbillonnant et le mélange formé est allumé pour créer un front de flamme stationnaire depuis l'injecteur. Pendant que l'injection se poursuit, s'opère un autre mélange destiné à alimenter le front de flamme qui le brûle à la même vitesse.

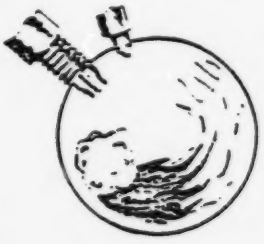
Fig. 1 LE SYSTÈME DE COMBUSTION CONTRÔLÉE DE TEXACO (SCCT)



Le tourbillon d'air créé par l'orifice d'admission est intensifiée grâce à un piston doté de cuvette durant la course de compression. La combustion, amorcée par injection et par allumage positif, crée aussitôt un front de flamme depuis l'injecteur.

L'étincelle continue; le carburant est injecté à une vitesse contrôlée; l'air continue à être alimenté par le tourbillon devant se mélanger au combustible. Le front de flamme est créé et la pression dans le cylindre se fait à une vitesse contrôlée.

Sans étincelle; l'injection continue à mélanger le combustible avec l'air alimentant le front de flamme.



Arrêt de l'injection; le front de flamme perd de son intensité, mais la combustion continue jusqu'à ce que tout combustible soit complètement brûlé. Le résultat est une brûlure propre d'un mélange pauvre dégageant moins de gaz.

Beaucoup de caractéristiques du moteur à injection directe et à charge stratifiée découlent du concept étudié ci-dessus. Le fait de commencer l'injection peu avant l'allumage élimine la possibilité de cliquetis par préallumage quelque soit l'indice d'octane du carburant. Cette caractéristique de l'allumage positif permet de se passer de l'indice de cétane requis pour le carburant ou des taux de compression élevés associés au moteur diesel. Il est aussi évident que la régulation de la charge peut se faire par un simple contrôle de la quantité de carburant admise sans utiliser un régulateur d'entrée d'air. Les moteurs à injection directe et à charge stratifiée illustrent l'économie dont font preuve les moteurs consommant des mélanges pauvres.

La présence du tourbillon d'air dans la chambre de combustion est l'une des conditions nécessaires au bon fonctionnement du système, la vitesse de rotation de l'air ayant une influence directe sur la durée de la combustion, et par voie de conséquence, sur le rendement du moteur.

L'expérience a révélé que bien que le rendement thermique s'accroît avec l'élévation du taux de compression, les améliorations marginales sont en réalité moindres pour les taux dépassant le voisinage de 12:1, au fur et à mesure que les frottements mécaniques et les autres déperditions augmentent.

Un travail théorique et pratique approfondi a permis d'établir la dimension et les proportions optimales de la cuvette pour chaque fonctionnement donné. Le piston idéal a été ainsi conçu comme ayant des parois parallèles et un fond plat mais ce profil n'est en aucun cas caractère limitatif.

4.2 Éléments spécifiques du moteur

L'application du principe du moteur à injection directe et à charge stratifiée à un moteur de conception spécifique implique:

- La modification de la culasse afin qu'elle s'adapte à la forme géométrique requise de l'orifice d'admission, à l'injecteur et au nouvel emplacement de la bougie.

- L'approvisionnement d'un système d'injection approprié.

- L'approvisionnement d'un procédé d'allumage approprié avec une distribution (minuterie) adéquate.

- La modification des pistons de façon à épouser le profil requis de la cuvette.

- Modification des parties du moteur dont le rôle est crucial au bon fonctionnement du nouveau système afin qu'elles puissent s'adapter à la culasse, au système d'injection, à celui de l'allumage à la soupage, au dispositif de commande et au changement des pistons.

Donc, chaque type de moteur implique sa propre série de modifications et il n'existe pas une solution unique pour plus d'un moteur.

4.3 Application du principe du moteur à injection directe et à charge stratifiée au moteur de la Ford 300

L'application fondamentale de la technologie du moteur à injection directe et à charge stratifiée à un moteur a été entreprise par Texaco Inc pour déterminer les paramètres de modification de conception de base. Ainsi pour l'alésage de 4.00 p. et la course 3.98 p. du moteur Ford, l'emplacement et la forme des orifices d'entrée et de sortie, celui de la bougie, la position et l'orientation de l'injecteur furent déterminés. C'est également ainsi que le profil de la couronne du piston ainsi que le contrôle de distribution ont été fixés par Texaco. La conception qui en a résulte reposait sur une combinaison d'études théoriques et d'une interpolation de données empiriques existantes dérivées d'essais précédents sur une grande variété de moteurs et de profils d'organes.

Ces études ont déterminé les modifications nécessaires à l'adaptation de la culasse existante à la nouvelle forme de l'orifice d'admission, à la bougie dont l'emplacement a été changé, à l'injecteur, au profil de la nouvelle chambre de combustion et au nouvel emplacement des soupapes. Au cours de cette étude, il a été constaté que ces modifications de formes pouvaient être faites sans qu'il ne soit nécessaire de modifier le bloc moteur ou les boulons de fixation de la culasse, exception faite des orifices des tiges de poussoir.

L'étude des soupapes a permis d'établir que les tiges de poussoir des soupapes devaient être réalignées, ce qui créerait une interférence potentielle au niveau supérieur du bloc. Cela fut surmonté en alésant les trous des douze tiges de poussoir. L'utilisation des culbuteurs à billes goujonnés fut considérée puis abandonnée pour des problèmes de formes. Un simple remplacement de l'arbre à cames permettrait le changement nécessaire du calage de distribution.

SYSTÈME DE COMBUSTION CONTRÔLÉE
CONVERSION DE MOTEUR

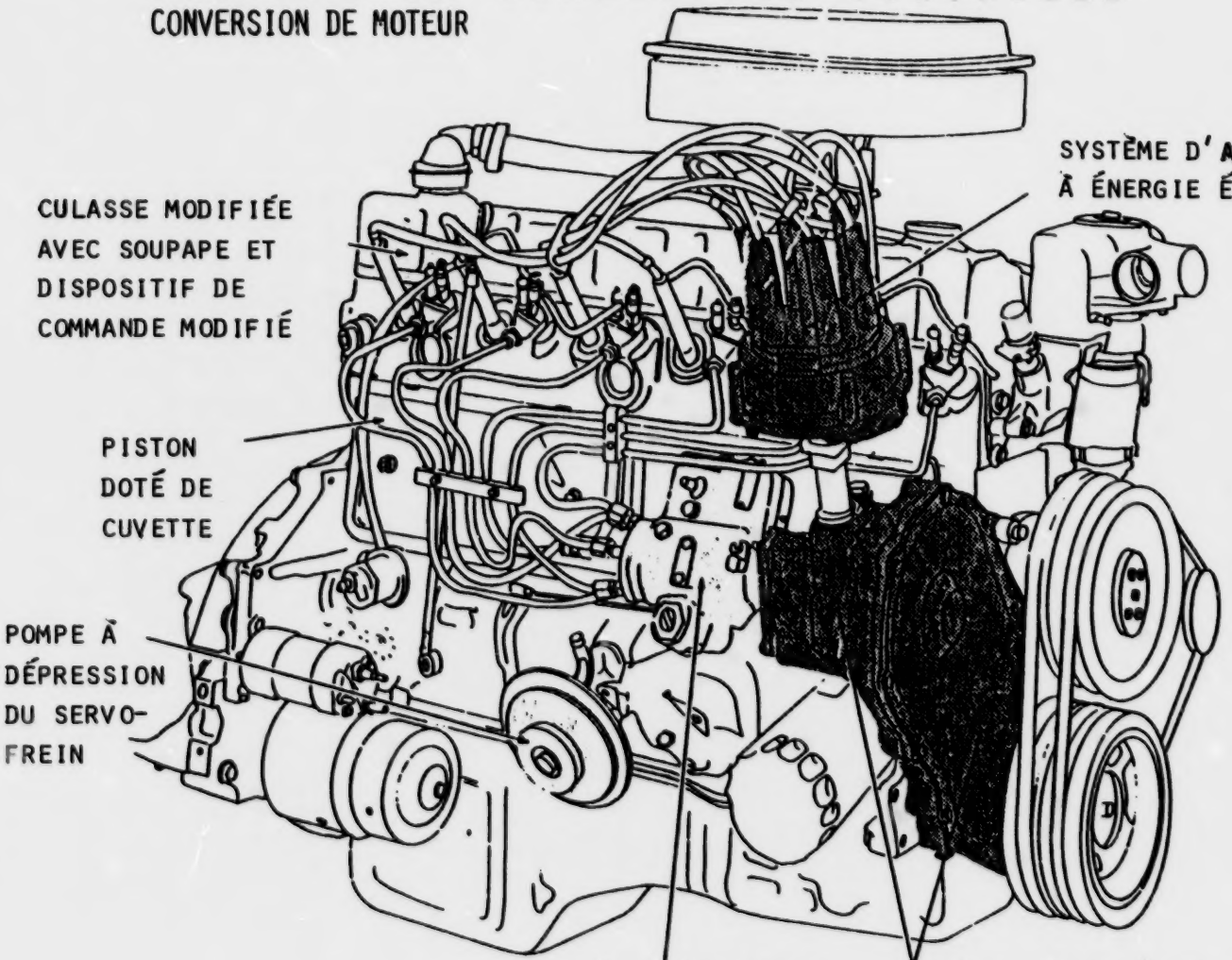


Fig. 2

Le remplacement du présent système de carburation par un système d'injection exige une autre commande de distribution, une pompe d'alimentation et un injecteur.

Le maintien de l'étincelle durant toute l'impulsion du carburant d'allumage impose des exigences rigoureuses au système d'allumage. Donc un nouveau système d'allumage à énergie considérable est aussi nécessaire étant donné qu'il est physiquement plus grand que le système d'allumage classique. Ces éléments sont montrés à la figure 2. Les dimensions du compartiment moteur d'un camion Econoline ont été examinées et il a été établi qu'il n'existe pas de problème d'espace pour le montage de ces éléments.

L'étude des exigences du re-profilage de la tête du piston a cependant révélé un problème classique quant à l'évolution de la conception des moteurs, en l'occurence la hauteur limitée du bloc moteur. Le concept de grande vélocité angulaire du tourbillon de cylindres au point mort haut du piston implique l'introduction d'une cuvette de forme spécifique dans la tête du piston. Sur le plan de la structure, puisque l'épaisseur de la tête du piston et la distance entre le bas de la couronne et le diamètre extérieur de l'axe du piston sont proches du minimum, le re-profilage nécessaire du piston ne peut se faire qu'en agrandissant le bord annulaire de la tête du piston par rapport à l'angle de l'axe de ce dernier, faisant remonter la tête du piston jusqu'au dessus du pont du bloc moteur. Dans le cas présent, la saillie était de 0.375 p.

Huit solutions directes aux problèmes de conception furent étudiées pour surmonter cette situation:

1. Culasse contre-alésée
2. Culasse alésée avec piston échelonné
3. Culasse et piston avec l'angle de couronne correspondant
4. Bielle de connection raccourcie
5. Bloc cylindre chemisé pour réduire le diamètre d'alésage
6. Cuvette de cylindrée réduite
7. Profil modifié de la cuvette du piston
8. Révision de la conception du vilebrequin

De toutes ces possibilités seules les solutions 7 et 8 ont été techniquement et économiquement viables. Le profil modifié de la cuvette ferait intervenir des variables inconnues d'où davantage de travail d'élaboration et de risques. Un nouveau vilebrequin impliquerait des quantités connues durant la construction mais cela mènerait à l'élévation du coût du produit fini. Un plan de construction logique continuerait l'application de ces deux solutions avec le nouveau vilebrequin pour parer à l'imprévu.

Une première conception de moteur destinée à servir de base à des travaux futurs a résultée de ces études de la géométrie fondamentale du moteur. La description de ce dernier, les nouveaux facteurs de production et l'usinage, ainsi que les spécifications du véhicule figurent aux tableaux 1-4 inclus.

TABLEAU 1 PARAMÈTRES DE BASE DE CONCEPTION DU MOTEUR

Pression cylindrique	1000 lb/po^2 (livres par pouce carré)
Taux de l'augmentation de pression cylindrique	60 lb/po^2 par degré du vilebrequin
Vitesse du moteur	3000 tr/min. (max.)
Taux de compression	12.0 (environ)
Rapport alésage du cylindre/ diamètre de la cuvette du piston	2.0 (min.)
Rapport longueur de la bielle/ rayon du vilebrequin (L/R)	3.1 environ (min.)
Diamètre de l'axe de piston	0.97 pouces (min.) par moteur stock Ford 300
Saillie de l'axe du piston à partir du bas de l'orifice du cylindre (alesage) point mort bas	diamètre de l'axe x 0.25 (max.)
Épaisseur du fond plat de la cuvette	0.25 pouce (min.)
Spécifications du système d'allumage	Distribution déclenchée par injecteur
	Étincelle contimue sur le parcours de 20 à 40 degrés du vilebrequin Parasites des fréquences de la radio à maintenir au minimum.
Spécifications du système d'alimentation en carburant	Fonctionne à l'essence, au diesel ou au mélange de deux combustibles "broad cut".
	Fonctionnent au méthanol et à l'éthanol grâce à des modifications du système (à définir).

TABLEAU 2 NOUVELLES PIÈCES REQUISES POUR LE KIT DE CONVERSION DU MOTEUR

Quantité	Description	ou Outillage requis (O) Pièce standard (S)	Catégorie de matière
1	Vilebrequin	O	acier forgé
6	Bielles	O	acier forgé
6	Pistons	O	fonte d'aluminium
6 jeux de	Segments	S	fonte d'acier
1	Culasse	O	fonte
2	Collecteurs d'échappement	O	fonte
2	Tublure d'admission	O	fonte
1	Arbre a cames	O	fonte
1	Cache-soupapes	O	fonte d'aluminium
1	Carter de pompe à injection	O	acier estampé
1 jeu de	Divers support et plaques de couverture	O, S	acier estampé
1	Système d'allumage	S	-
1	Soupape et dispositif de commande	S	-
1	Pompe à dépression	S	-
1	Système d'injection, commande de pompe comprise	S, O	-
1 jeu de	Filtres à air et à carburant, carters compris	S	-
1	Thermostat et des modifications du système de refroidissement	S, O	-
1 jeu de	Joints d'étanchéité	S	-

TABLEAU 3 OUTILLAGE MAJEUR REQUIS

Pièce	Usinage	Prototype	Production
Pistons (forgeage)	étampes	X	X
Vilbrequin (forgeage)	étampes		X
Bielles (forgeage)	étampes		X
Supports et plaques de couverture (martelage)	étampes		X
Culasse (moulage)	boîtes à coulage modèles	X	X
Tubulure d'admission	"		X
Collecteur d'échappement	"		X
Cache-soupapes	"		X
Carter à cames	"		X
Carter de thermostat	"		X
Carter de pompe à injection	"		X

TABLEAU 4 SPÉCIFICATIONS DU VÉHICULE

Les spécifications suivantes furent élaborées en consultation avec Purolator Courier Ltée, propriétaires d'une flotte des camions de livraison Econoline, sur la base de l'expérience qu'il ont eue du moteur Ford 300.

Véhicule d'essai	Camion Econoline de Ford
Poids total chargé	7000 lb (livres)
Poids réel à vide	1800 lb (livres)
Cycle de mileage, de l'est du Canada	35 % zones urbaines 65 % autoroutes
Nombre de chevaux requis (approx.)	100
Tours par minute (max)	3000
Type de transmission	Automatique, 3 vitesses
Température minimale de démarrage en temps de froid	- 20°F
Changement d'huile de moteur et de filtre	8000 mi
Mise au point des accessoires	16,000 mi
Ré-usinage du moteur	120,000 mi

5.0 ÉVALUATION COMMERCIALE ET FAISABILITÉ ÉCONOMIQUE

5l Rendement pour l'usager

Du point de vue des services que ce type de véhicule peut rendre, le moteur à injection directe et à charge stratifiée sera très bien accueilli sur le marché des camions légers de petite vitesse en usage dans les zones urbaines à cause de la prédominance des véhicules légers actuels dont les moteurs s'allument à l'étincelle et brûlent de l'essence (et du propane récemment). Ces moteurs souffrent d'énormes pertes de pompage dûes au réglage d'admission résultant de leur opération normale à petite vitesse. Le moteur à injection directe et à charge stratifiée convient mieux à ce marché de véhicules pour diverses raisons abordées plus haut mais aussi à cause d'un avantage particulier sur les moteurs à diesel en termes de facilité de conversion de véhicules.

5.2 Potentialité de Conversion

La possibilité d'une conversion du moteur à injection directe et à charge stratifiée est un sujet d'intérêt considérable pour les propriétaires des flottes de camions légers à en juger par le nombre de sollicitations faites à Texaco par les plus importants d'entre eux aux États Unis.

Une brève enquête sur les potentialités du moteur à injection directe et à charge stratifiée menée auprès des utilisateurs de flotte de camions de livraison du Canada et qui constitue une partie de cette étude a produit une réponse tout aussi positive. Une importante découverte faite au cours de cette enquête est que les propriétaires de grandes flottes de camions de livraison tendent à refaire les moteurs plusieurs fois par intervalles de 80,000 à 120,000 miles pendant la vie du véhicule, en faisant ainsi des candidats ideaux pour une conversion massive des moteurs à injection directe et à charge stratifiée.

Parmi les principaux propriétaires de flottes du Canada utilisant le moteur de la Ford 300, figurent vingt-deux sociétés dont cinq furent contactées comme représentants, elles ont été interviewées durant cette étude. Ces sociétés ont constitué l'objet de l'étude non seulement à cause de leur propre expérience mais aussi pour leurs connaissances des pratiques industrielles générales. Les suppositions exprimées dans cette section ont été basées sur des données d'étude.

Le volume global de ventes potentielles de conversions destiné aux camions canadiens équipés de moteurs Ford 300 a été estimé pour chaque année civile jusqu'en 1983, leurs résultats sont illustrés à la figure 3. Les ventes potentielles annuelles moyennes de conversions au Canada sont d'environ 15 000 véhicules, à supposer que l'espérance de vie moyenne du véhicule soit de 7 ans et que 50% des moteurs de véhicules soient refaits après 4 ans de service. Les potentialités pour les États Unis (figure 4), également basées sur des chiffres d'affaires réalisés dans le passé, sont 10 fois plus élevées (150 000 véhicules par an), en plus, la taille d'une flotte moyenne étant plus grande qu'au Canada.

5.3 Ventes potentielles du matériel d'origine

Les données fournies par Ford ont servi à préparer la figure 5 qui montre la relation entre chiffres d'affaires et primes pour les options de matériel de première monte de camions légers offrant diverses facilités d'amélioration de la consommation de carburant en zone sub-urbaine (divers). Il est à noter que cette donnée ne s'applique qu'aux marchés sensibles aux fluctuations des prix et non à ceux qui achètent aux coûts les plus bas quels que soient les coûts de service. Aussi aucun crédit n'a-t-il été accordé pour les avantages secondaires tels que entretien réduit, meilleure performance en temps de froid ou aptitude à consommer plusieurs carburants.

En ce qui concerne le moteur fonctionnant à l'essence, la figure 5 indique qu'une petite partie du marché de l'outillage d'origine des camions légers pourrait être gagnée sur la base de coûts additionnels de US $2 000 à US $3 000 projetés pour un moteur à injection directe et à charge stratifiée. L'amélioration de la consommation de carburant par les moteurs brûlant du diesel ou des carburants "broad cut" permettra une meilleure pénétration du marché si bien qu'un produit tel que le moteur à injection directe et à charge stratifiée serait très compétitif par rapport à l'équipement des moteurs à diesel et à propane de première monte.

Fig. 3 . VENTES POTENTIELLES D'ÉQUIPEMENT DE CONVERSION SUR LE MARCHÉ CANADIEN CAMIONS FORD 6 CYL.

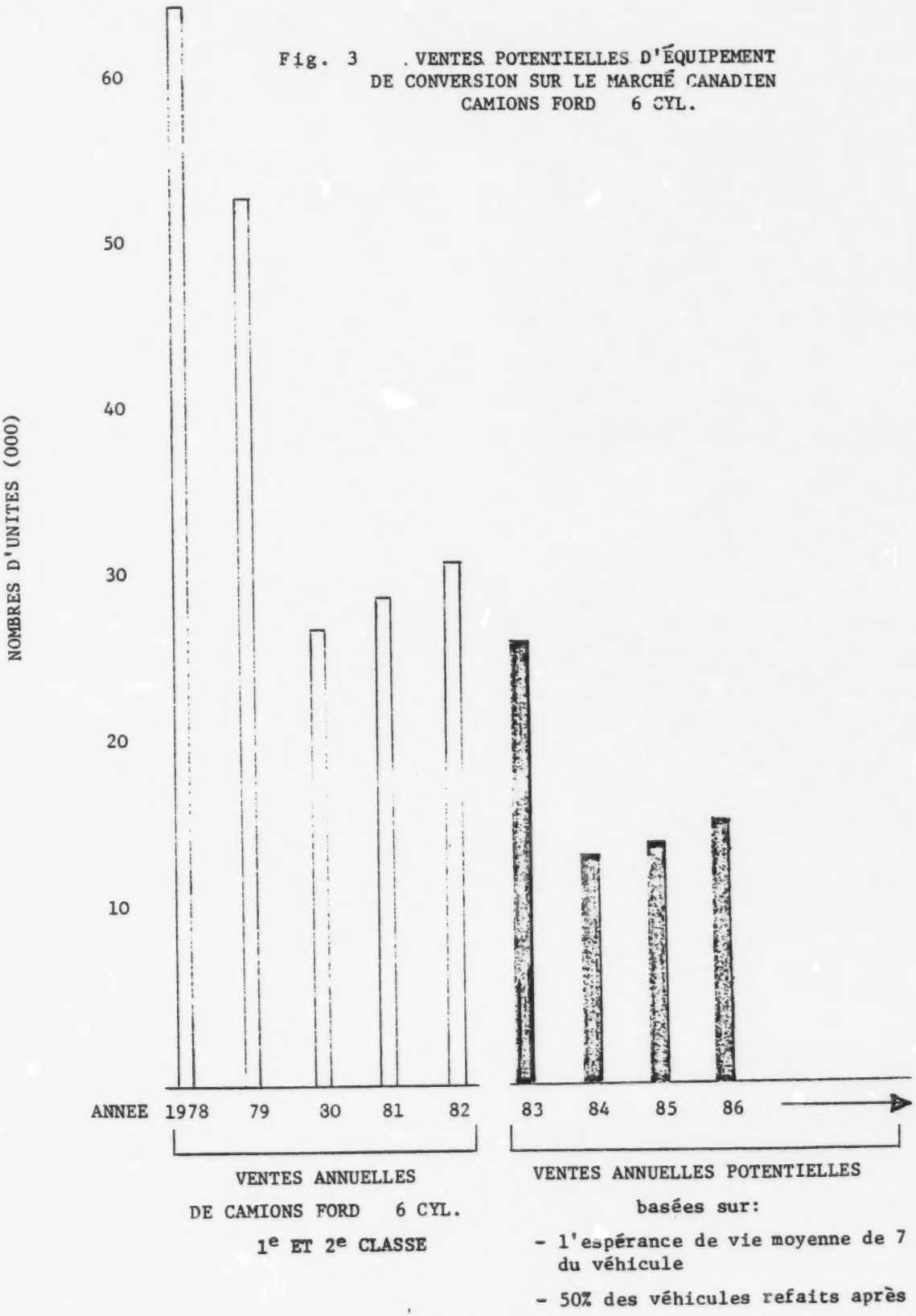
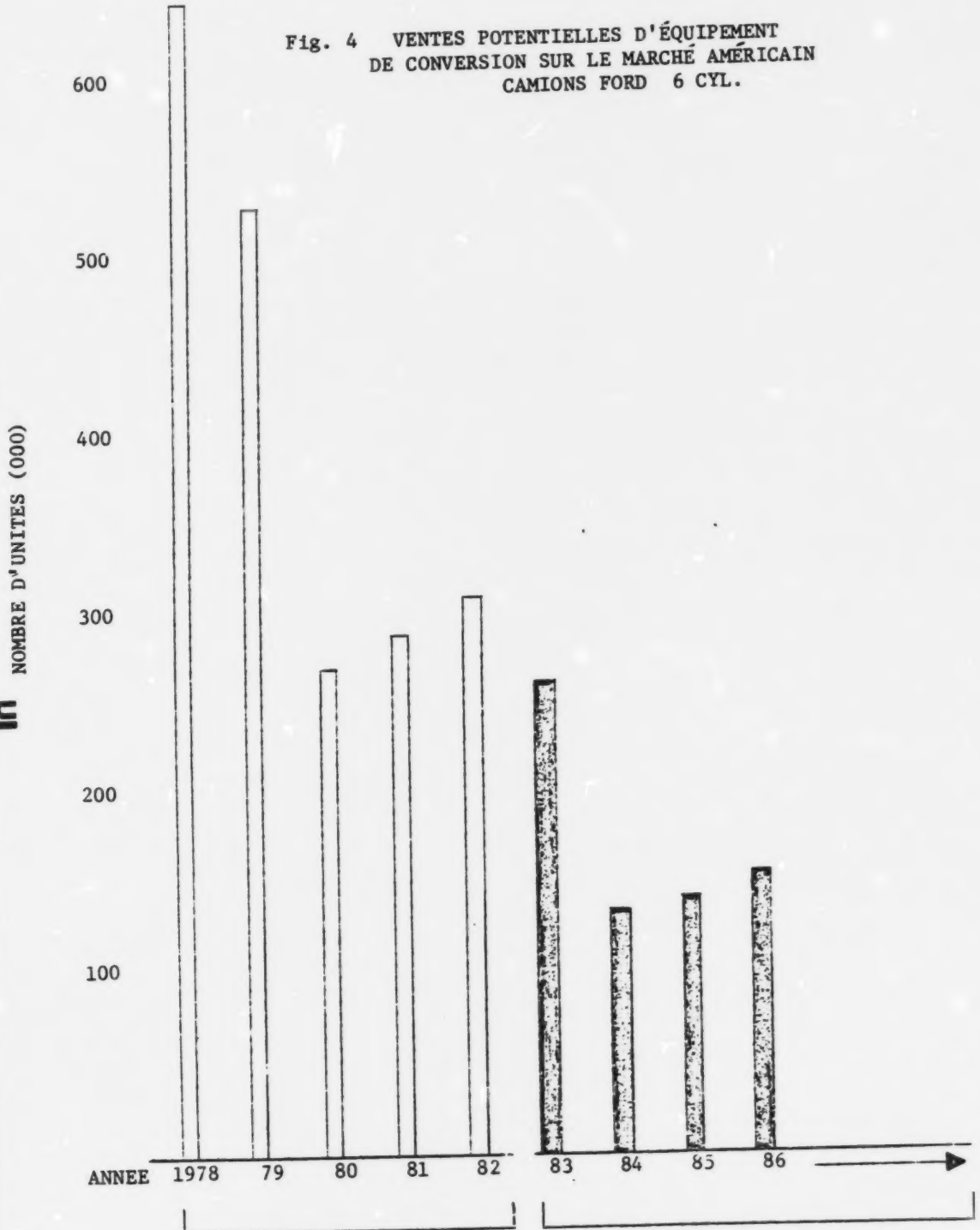


Fig. 4 VENTES POTENTIELLES D'ÉQUIPEMENT
DE CONVERSION SUR LE MARCHÉ AMÉRICAIN
CAMIONS FORD 6 CYL.



6.0 CONCLUSIONS ET RECOMMANDATIONS

6.1

La technologie du moteur à injection directe et à charge stratifiée mise au point par Texaco a été étudiée et son application au moteur à 6 cyl. de la Ford 300 a été considérée comme techniquement faisable.

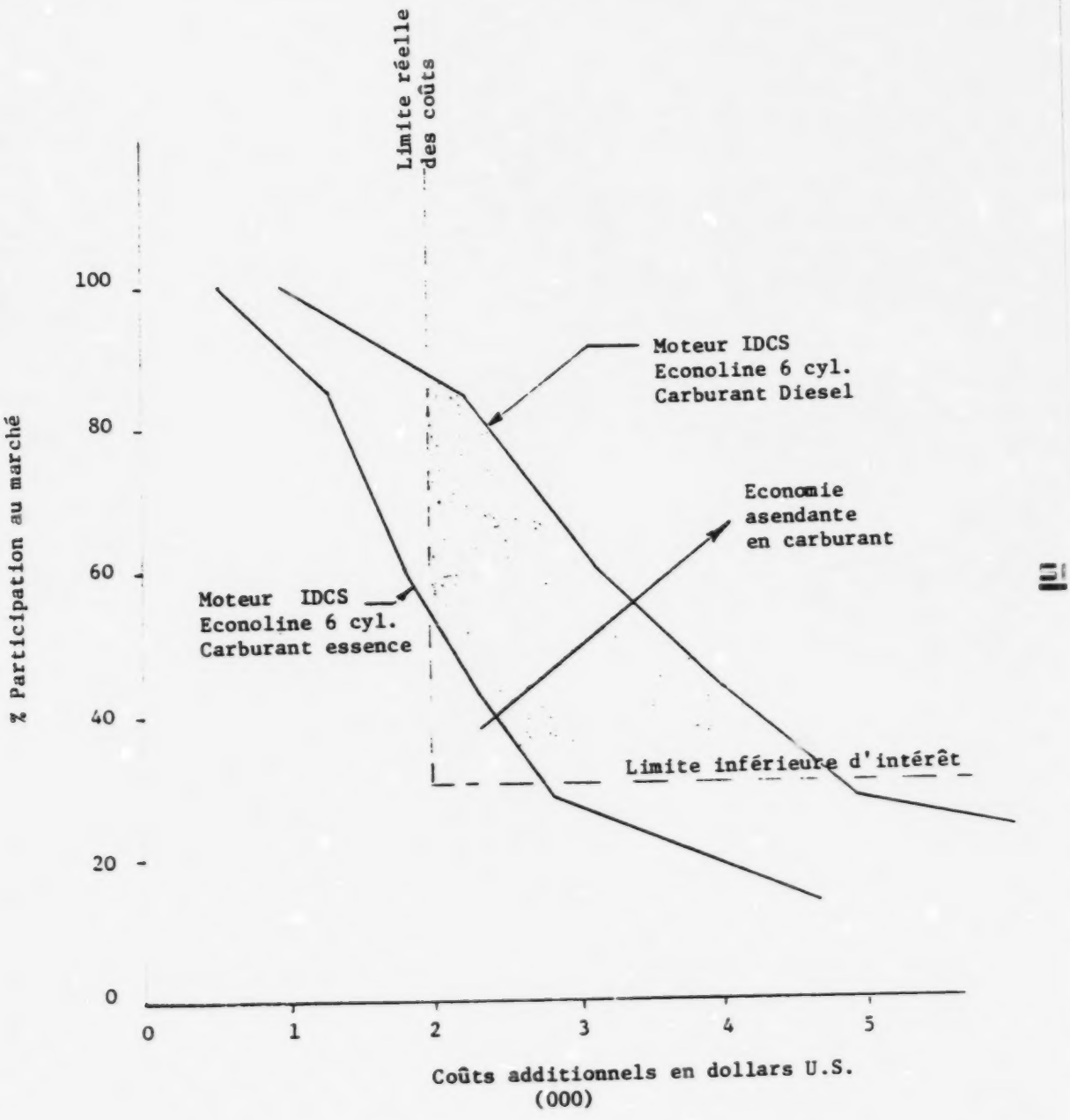
6.2

Les aspects commerciaux d'un programme adéquat de commercialisation du moteur ont été évalués et ont été considérés comme viables. Il s'agira de trouver un constructeur canadien de matériel de première monte pour la mise en oeuvre d'un tel programme.

6.3

Il a été trouvé un programme de développement utilisant des ressources canadiennes visant à mettre au point une conception de moteur d'avant garde avec le moins de risques possible. Ce programme devrait être poursuivi jusqu'au stade de la construction du prototype afin d'assurer une capacité de développement du moteur à injection directe et à charge stratifiée dans le contexte d'une "technologie de contingence" à la portée des Canadiens.

Fig. 5 VENTES/COÛTS ADDITIONNELS



Basés sur:
- secteur du marché sujet à des fluctuations de prix
- période de remboursement de 2 ans
- cycles divers (60% zones urbaines)
  (40% autoroute)

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3

DIRECT INJECTION STRATIFIED CHARGE

ENGINE DEVELOPMENT

Final Report

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DIRECT INJECTION STRATIFIED CHARGE ENGINE DEVELOPMENT

FINAL REPORT

by

F.W. Eyre and P. Nikolaiczuk

SNC Inc.

for the Transportation Development Centre

December 1982

SNC # 6427

The contents of this report reflect the views of the contractor and not necessarily the official views or policies of the Transportation Development Centre of Transport Canada.

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17 Abstract

Significant reductions in fuel consumption can be realised through the use of direct fuel injection internal combustion piston engines operating on the stratified charge principle. The DISC engine technology, developed by Texaco Inc., can be adapted to existing vehicle engines on an original equipment supplier or retrofit basis, and permits the use of a wide range of engine fuels, thereby allowing an increase in refinery efficiency. In this study, the means of converting the Ford 300 6-cylinder engine to DISC operation, supplier network, user potential, and preliminary economics were evaluated. Subject to test confirmation of proposed design changes, the engine conversion was found to be potentially viable. The engine could be produced in Canada in retrofit form. A plan for subsequent programs leading to volume manufacture was outlined.

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15. Remarques additionnelles	16. Agent de projet — CDT
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17. Résumé

L'adoption du moteur à pistons et à combustion interne, equipé d'un système à injection directe et fonctionnant selon le principe de la charge stratifiée, peut permettre d'importantes réductions de la consommation de carburant. La technologie du moteur à injection directe et à charge stratifiée, élaborée par Texaco Inc. peut être adaptée sur les moteurs de véhicules existants, soit par le constructeur d'équipement de première monte, soit en les réadaptant à cette nouvelle technologie, ce qui permet d'utiliser une grande variété de combustibles pour moteur, augmentant ainsi le rendement global des raffineries. Cette étude décrit les moyens de convertir le moteur Ford 300 à 6 cylindres de sorte qu'il puisse fonctionner sur le principe du moteur à injection directe et à charge stratifiée. Le réseau de distribution, les potentialités qu'il recèle pour son utilisateur et l'évaluation économique préliminaire ont été évalués et le concept prouvé rentable. Un plan de programmes ultérieurs de construction à grande échelle a été conçu.

18. Mots-clés	19. Diffusion
Conception des moteurs, moteur à pistons automotive, charge stratifiée, injection directe	Le CDT dispose d'un nombre limité d'exemplaires

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SUMMARY

This report presents the results of a study sponsored by the Transportation Development Centre of Transport Canada to investigate the technical and economic feasibility of the application of direct injection stratified charge technology to a selected highway vehicle powerplant, in this case the Ford 300 engine having 6 cylinders.

The stratified charge technology has been developed by Texaco Inc. for use on conventional piston engines, and utilizes a coordinated arrangement of fuel injection, positive ignition and air swirl within the combustion chamber to permit the use of lean fuel/air mixtures and a range of alternative fuels including diesels, alcohols, and broad boiling range fuels in addition to gasoline.

This study represents the first of several phases comprising the overall program, which is planned to include the design and construction of a prototype converted engine, dynamometer and vehicle testing in fleet service, market and economic evaluation, and production planning leading to eventual manufacture of engines.

An important part of the program would be the evaluation of engine performance on a selection of petroleum-based fuels and evaluation of operation on methanol.

Overall objectives of the program include:

- Contribution to the National Energy Program
- Development of engines for future multifuel capability
- Transfer of technology to Canadian design teams
- Gain access to US market through specific technology
- Increased production of Canadian engines and components

The project team was headed by SNC Inc., providing the functions of program management, coordination and economic evaluation. Texaco Inc. furnished the basic technology and Ontario Research Foundation assisted in the design work and program planning. Ford Motor Company supplied drawings, engineering advice and market information. Purolator Courier Ltd., a fleet user of the Ford 300 engine, helped establish performance requirements and is scheduled to provide in-service testing of the converted engines.

SUMMARY (cont'd)

During the study, engine modification design requirements were outlined, followed by preparation of preliminary design drawings and recommendations. Potential component suppliers were contacted, tooling requirements were established and a plan for further work was prepared, including engine design, construction and component testing requirements with an estimate of costs involved.

The results of the study indicate that direct injection stratified charge technology can be successfully applied to the Ford 300 engine and that the economic and market aspects of an appropriate commercialization program are viable. It is recommended to identify a suitable Canadian manufacturing agency and to pursue the program to the prototype engine stage to ensure a development capability in the context of a "contingency technology" available to Canadians.

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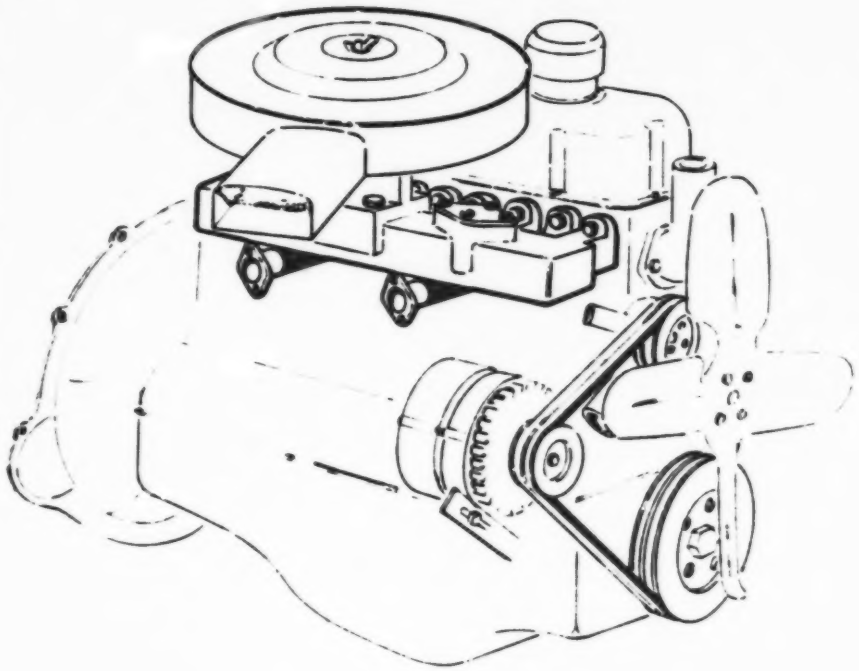
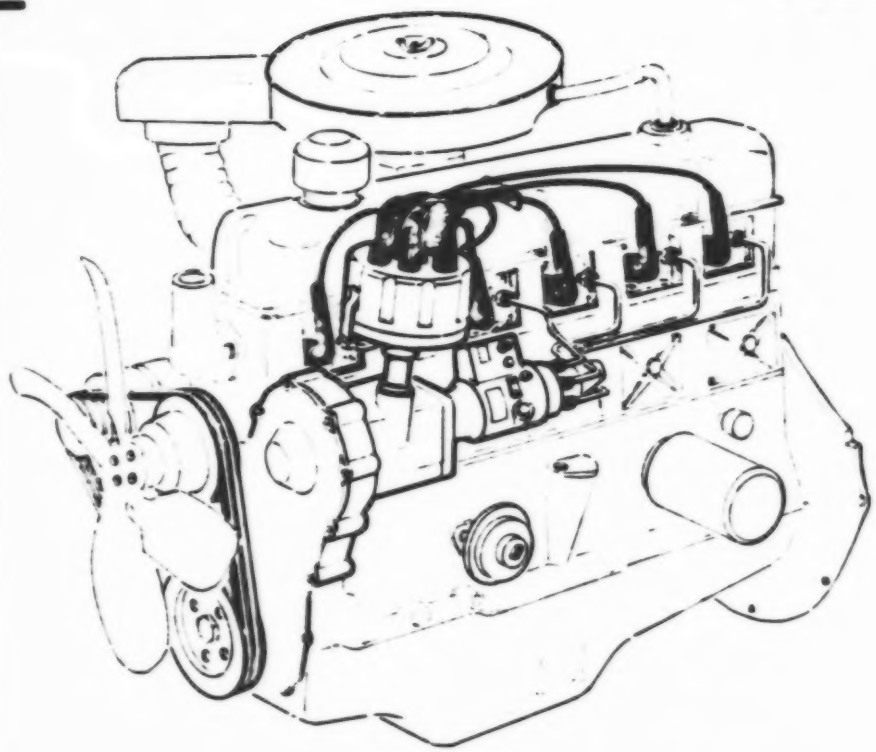
6427-0000-45DD-0004	SNC Ford 300 CID - TCCS Conversion
8441-0000-3200-001	SPEC Network
CS-D-6110	SNC Ford 300 TCCS - Layout
CS-D-6116	SNC Ford 300 TCCS - Valve Geometry
-	Engine Compartment Dimensions



Ford 300H
TCCS Version



1.0 INTRODUCTION AND ENGINE SELECTION

Among the many scenarios anticipated for vehicular highway transport, all but the most extreme anticipate that the conventional internal combustion engine, with appropriate development, will remain a primary power plant through till the end of the present century.

Present engine design trends indicate that increasing emphasis will be placed on fuel saving, energy conservation and reduced exhaust pollutants. A further desirable development would be the capacity for future engines to operate on the wide range of fuels presently promoted as alternatives or extenders to conventional crude oil derived gasoline.

The Direct Injection Stratified Charge (DISC) engine is an excellent example of such development. In fact, numerous transportation fuel studies indicate that the DISC concept as applied to contemporary piston engines will eventually dominate the alternative fuels engine market.

The concept, which has been under development by Texaco Inc. since the early 1950's, utilizes a coordinated arrangement of fuel injection, positive ignition and air swirl within the combustion chamber to yield "patch burning" of a combustible mixture. The resulting ability to burn unthrottled, overall lean fuel/air mixtures produces engines having excellent fuel economy with inherently low emissions of exhaust pollutants. The technology is also compatible with high compression ratios and inlet pressure charging.

Equally important, the unique coordinated arrangement prevents combustion knock without regard to fuel octane rating and ensures smooth ignition without regard to cetane rating. This fuel tolerance capability allows DISC engines to operate on a variety of fuels, including gasoline, diesel fuel, alcohols and broad boiling range (broad-cut) fuels. The latter category of engine fuels is especially interesting, since production of broad-cut fuels allows a refinery to increase the amount of fuel recoverable from a given quantity of crude oil thereby increasing the available supply of engine fuels. The concept of vehicle fuel/refinery interaction is described in greater detail in Appendix C.

Further advantages of the DISC engine concept, characterized by the TCP (Texaco Combustion Process) and subsequently the TCCS (Texaco Controlled Combustion System), include the facility of its application to existing engine designs and production line tooling, thereby reducing the long, costly new engine development process. DISC hardware also has the potential to be economically retrofitted to existing vehicles, notably light delivery trucks in fleet service.

It must however be recognized that although the principle is conceptually applicable to any engine - gasoline or diesel - each specific application involves a particular set of constraints, and each engine design has to be evaluated separately on its own merits.

By comparison with diesel engine vehicle installations, the DISC engine is lighter, cheaper, more flexible and just as efficient. In one retrofit comparison (based on actual cost experience by United Parcel Service) the total cost of installation of a DISC engine retrofit kit was identified at US $2,500. The comparable diesel retrofit costs were over US $6,000 and involved changes to the power train and front suspension, in addition. Furthermore the diesel engine offered no relief from spot fuel shortages, whereas the DISC engine can operate on any grade of gasoline, or diesel fuel.

Despite the attractiveness of the DISC concept and the extent of work conducted, there has to date been no widespread application, and virtually no work done in Canada. The reasons have varied during the evolution to the present advanced status of the pertinent technology. Initially (1950's, 1960's) the engine market emphasis was for increased power followed by concern for pollution control, and then a concerted industry effort with respect to vehicle safety. The "energy crisis" has seen a diffused industry effort covering a wide spectrum of activities with a general trend to vehicle down-sizing in response to market demand. However, Texaco Inc. and United Parcel Service (UPS) are currently conducting a prototype DISC engine evaluation program based on the General Motors 292 cubic inch engine installed in UPS delivery vans. Test results to date are encouraging, with fuel economy being improved by approximately 30% under city driving conditions.

The SNC Group has followed the evolution of the work done by Texaco, with this interest resulting in the submission of a proposal by SNC to the Government of Canada for a study in several phases of the DISC concept applied to a suitable engine having Canadian production potential.

After careful consideration, the Ford 300 cu. in. 6 cyl. engine, currently installed in the Ford Econoline Van and Pickup, was selected for study. This engine was chosen as a unit in widespread use with a 15-year history of reliable service, and which, with current production of 50,000 units/year and growing, promises to make it the most popular gasoline truck engine in Canada. U.S. experience, proportionally greater, parallels Canadian trends. It derives from a family of engines and a design philosophy for robustness which portend operation without problems at the relatively high compression ratio which the DISC application would involve.

This report details the results of a study to define the technical and economic feasibility of a stratified charge engine package applicable to the selected Ford engine.

The overall project has been planned to follow this initial study by sequential phases comprising detail design, bench testing, fleet installation and evaluation, followed by eventual production implementation. SNC Inc. will provide overall project management and coordination, and will undertake economic evaluation; Texaco Inc. will provide the basic technology; Ontario Research Foundation will participate in the design work and will perform development testing of prototype engines and components.

Purolator Courier Ltd. will actively participate in establishing performance requirements for the modified engine and will provide services for fleet evaluation of the finished product.

Throughout the body of this report the foot-pound-second system of units has been used in preference to metric units, consistent with continuing practice in the North American engine component parts industry.

2.0 PROGRAM OBJECTIVES

2.1 Overall Objectives

2.1.1 Contribution to the National Energy Program

Development of DISC technology is compatible with the NEP objectives of promoting the use of alternative fuels which will replace gasoline, increasing the efficiency of energy use, reducing Canada's dependence on imported oil, and shifting Canadian refineries' output to an overall product mix featuring a more efficient use of domestic low-grade crude oil.

In addition, the DISC engine's fuel tolerance characteristic would encourage regional upgrading of petroleum resources, further contributing the overall economies in the national refining process.

2.1.2 Development of engines for future multifuel capability

Although not yet commercially available in quantity, the advent of broad-cut diesel and alcohol fuels will cause gasoline to lose its predominance as the principal vehicle engine fuel. As new engine concepts typically require 5-10 years for complete development to marketable status, the need exists for multifuel engines such as the DISC engine to be designed and developed at this time.

2.1.3 Transfer of technology to Canadian design teams

The DISC engine program would firmly establish a Canadian technological capability for fundamental engine design in addition to integrating a prototype engine fabrication network.

2.1.4 Gain access to U.S. market though specific technology

As demonstrated by the success of other Canadian export programs featuring products incorporating specific technology (gas turbine engines, telecommunications systems, etc.), certain products can indeed be developed in Canada to satisfy new market openings in the U.S. and abroad.

2.1.5 Increased production of Canadian engines and components

The hardware comprising a DISC package would be produced in Canada using domestic raw materials, manpower, equipment and tooling. Appropriate control of the required tooling would ensure that production of DISC components would remain in Canada, regardless of the manufacturer or marketing agency.

2.2 Phase 1 Objectives

The Ford 300 engine has already been identified as the appropriate unit upon which to achieve the overall program objectives.

The objectives of this Phase 1 report are to define the technical and economic feasibility of the DISC engine package as applied to the Ford 300 6-cylinder engine, and to prepare a plan for an engine development program.

3.0 OVERALL PROGRAM

The overall engine program consists of four phases:

Phase 1 Preliminary feasibility study and program planning
Phase 2 Prototype engine design, build and bench testing
Phase 3 Fleet installation and evaluation
Phase 4 Production implementation

An integral part of the program is the evaluation of engine performance on a selection of petroleum - based fuels and evaluation of operation on methanol.

Concurrent with the prototype engine engineering program, economic and marketing studies have been planned to culminate in the negotiation of manufacturing and marketing agreements leading to product sales.

An executive plan in block diagram format for the overall program is illustrated in Fig. 1.

Phase 1 (covered by this report)

The principal activities of this phase were performed to ensure that the anticipated modifications to the Ford 300 engine were theoretically sound, to determine overall project economics, and to determine the development program necessary to achieve a technically and economically viable end product.

Given this foregoing design investigation it would be possible to prepare a development plan with estimated costs and schedule for the later phases.

Listed below are the specific Phase 1 activities, the results of which are detailed in following sections of this report:

- Definition of a detailed specific plan for conduct of the first phase.
- Establishment of agreement and commercial terms between participants.
- Definition of design requirements for engine mofification.
- Translation of design requirements into preliminary designs.

- Definition of design recommendations.

- Preparation of preliminary layout drawings.

- Preparation of a plan for implementation of subsequent phases.

- Estimation of user potential.

- Preparation of first phase final report.

Phase 2

Phase 2 includes preparation of manufacturing drawings, production of parts and construction of engines for bench testing, evaluation, and modification as necessary, and testing of the evolved design to determine fuel consumption, emissions, retrofit and service constraints, and to obtain initial wear estimates. Prototype service tests will be conducted. Identification of parts suppliers and a fleet evaluation plan will be developed concurrently.

This phase will include a preliminary market study and an economic analysis based on the prototype engine's measured performance and estimated production cost. Potential contractors and licencees will be identified during this phase of the program.

Phase 3

Phase 3 will cover a fleet installation of typically 20 vehicles operating over a full calendar year. These vehicles will be monitored together with a control group to compare fuel economy, service and maintenance requirements, and operating economics. In parallel with the fleet evaluation a production evaluation will be undertaken to finalize component and assembly costs.

A full market study will be completed, resulting in the development of a marketing strategy as a prelude to negotiating marketing agreements.

This phase will be completed by an evaluation report covering all work done including an updated economic analysis.

Phase 4

Phase 4 will include the initiation of engine manufacture and market introduction.

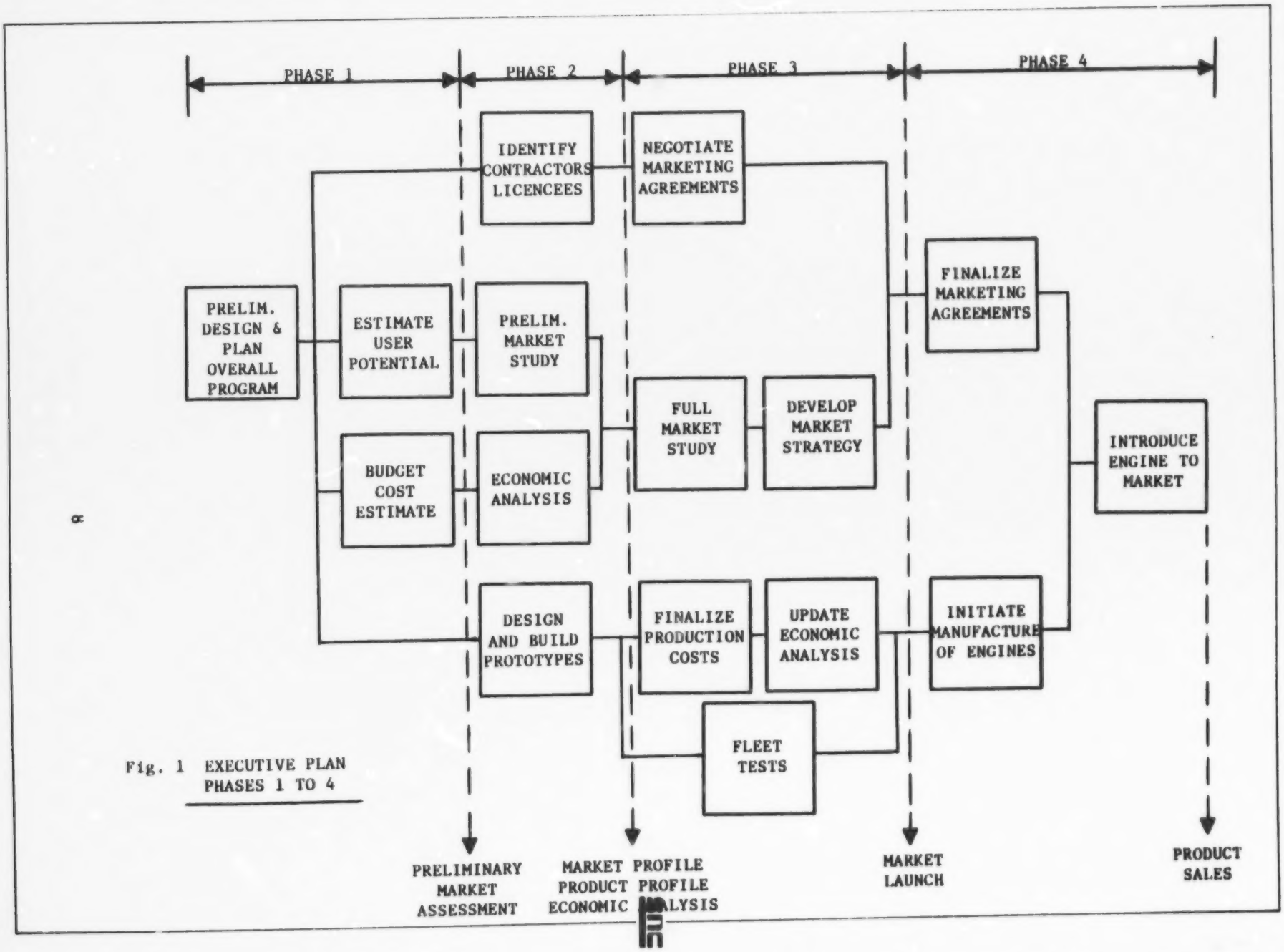


Fig. 1 EXECUTIVE PLAN
PHASES 1 TO 4

4.0 FEASIBILITY STUDY

4.1 General

The study was conducted in accordance with a SPEC planning network developed at the contract outset (see Appendix B dwg. 8441-000-3200-001) as a set of inter-related activities. These comprised classification of the TCCS principle, determination of the vehicle (and hence engine) performance requirements, application of the technology to the Ford 300 cu.in. displacement engine and translation of this information into assembly and component specifications of sufficient depth that the preliminary economics and methodology for future work could be ascertained.

Key elements of the technology transfer activity included the involvement of the pertinent agencies in all steps of the technology application and implementation process.

4.2 Study Team

The participants in this study included SNC Inc., Ford Motor Company, Texaco Inc., Ontario Research Foundation (ORF), and Purolator Courier Ltd. Their respective activities performed over approximately a one-year period are shown graphically on SPEC network dwg. 8441-0000-3200-001 and their responsibilities are described in detail in the following paragraphs.

4.3 Division of Responsibilities

SNC, being prime contractor, performed overall project management functions and held responsibility in such specific areas as planning Phase 1, alternate engine layout analysis, establishing tooling requirements, investigating potential suppliers' capabilities, formation of a procurement plan, visiting potential assembly facilities, establishing test requirements, performing market and economic analyses, identifying and negotiating with potential manufacturing and marketing partners, planning of subsequent phases of the program and report preparation.

Ford Motor Company provided engine drawings and limited engineering advice, including an in-depth engineering design session on their premises focussing on the basic engine layout. Ford also provided marketing information, sales statistics, purchaser lists, and market profile data.

Texaco Inc. acted as design authority, and specified the required combustion chamber dimensions, cylinder pressure characteristics, cylinder head layout, injection and ignition systems components and layouts, and valve characteristics. They also prepared non-dimensional scale drawings of pertinent engine sections and equipment relationships. Texaco, having an ongoing relationship with Ricardo Consulting Engineers Ltd. of England, coordinated a project meeting with Ricardo for the purpose of planning and costing a prototype engine development program.

For the first phase, ORF's main role consisted of assisting in the planning of engine testing and development and their major involvement was planned for the second and third phases, in which they would perform the bulk of the work. ORF also participated in design and Steering Committee meetings, and assisted in the preparation of the potential suppliers list and the planning of Phase 2. ORF's work report appears in Appendix E. Their specific design work included vehicle engine bay clearance checks.

Purolator also participated in several formal meetings, and supplied the project team with two engines and a complete vehicle for use in design work. Purolator also furnished fleet operation data and component selection recommendations based on their previous fleet maintenance experience.

A key element of the technology transfer activity comprised the involvement of the pertinent agencies in all steps of the technology application and implication process.

4.4 Meeting, Travel and Communications

During the performance of the study work, various meetings and visits essential to the project were organized by SNC. These events, totalling more than 17 in number, are listed in Table 1.

In addition, potential equipment suppliers, contractors and equipment associations were contacted and evaluated with regard to their experience, qualifications, facilities, and capabilities as applicable to the downstream program phases of prototype and production engine manufacture and testing. Table 2 contains a list of the names and locations of 50 of the selected parties contacted during the course of this feasibility study.

TABLE 1 MEETINGS HELD AND VISITS MADE DURING PHASE 1

Date	Location	Participants	Purpose
Nov. 4/81	Montréal	TDC, Tex, SNC, ORF, Purolator	SPEC plan and work agreements
Nov. 12	Dearborn, Mich.	SNC, Tex, Ford	Ford engine drawing review and transmission
Jan. 13/82	Beacon, N.Y.	Texaco, SNC, ORF, Purolator, TDC	Review design constraints
Feb. 24	Dearborn	Ford, SNC, ORF, Tex	Design discussion
Feb. 25	Detroit	Ricardo, SNC, ORF	Tech. Evaluation
Mar. 17	Montréal	SNC, SDRC	Stress analysis
Mar. 23	Montréal	SNC, Purolator	Tech. discussion
April 19	Montréal	SNC, ORF	Project review
April 22	Montréal	TDC, SNC, ORF	Steering Committee
June 2-3	Toronto	Ricardo, SNC, ORF Texaco	Discuss prototype design
July 7-8	Moline, Ill.	John Deere, SNC	Marketing discussion
July 23	Montréal	KHD, SNC	Assy. and marketing discussion
July 29	Toronto	SNC, ORF	Plan Phase 2
Aug. 5	Ottawa	TDC, SNC, ORF, Purolator	Steering Committee
Sept. 2	Montréal	SNC, ORF	Plan Phase 2
Sept. 20	Montréal	SNC, Mahle	Prototype develop. discussion
Oct. 8	Montréal	SNC, ORF, Perkins	Plan Phase 2

Table 2 POTENTIAL SUPPLIERS AND CONTRACTORS CONTACTED

Name	Location	Product or Service
Ford Motor Company	Dearborn, Mich.	Engineering support
Ford of Canada	Pte Claire, P.Q.	Marketing info.
Ford of Canada	Oakville, Ont.	Marketing info.
Texaco	Beacon, N.Y.	Design authority
Ricardo Consulting Eng.	England	Prototype engine design
A.V. List	Austria	Prototype engine design
A.I.R.	Switzerland	Combustion technol.
KHD/Deutz	Montréal	Engine assembly & test
Eastern Rebuilders	Bedford, P.Q.	Engine assembly & test
Central Precision	Rexdale, Ont.	Engine assembly & test
Cdn. Foundry Assoc.	Ottawa, Ont.	Lobby group
APMA	Toronto, Ont.	Lobby group
MVMA	Detroit, Mich.	Vehicle statistics
CAE-Montupet	Ste Catharines, Ont.	Aluminum castings
TRW	Noblesville, Ind.	Cylinder head castings
Mahle	Germany	Piston castings & forgings
SIFCO	Cleveland, Ohio	Crankshaft forging
Clifford Mfg.	Markette, Mich.	Engine assembly & test
CWC Mfg.	Muskegon, Mich.	Camshaft castings

Table 2 POTENTIAL SUPPLIERS AND CONTRACTORS CONTACTED (Cont'd)

Name	Location	Product or Service
Weyburn-Bartell	Grand Haven, Mich.	Camshaft machining
Stanadyne	Hartford, Conn.	Fuel injection systems
Robert Bosch	Detroit, Mich.	Fuel injection systems
Great Lakes Forgings	Windsor, Ont.	Connecting rod forgings
Wyman-Gordon	Jackson, Mich.	Crankshaft forgings
Kellog Crankshaft	Jackson, Mich.	Prototype crankshafts
Atlas Crankshaft	Fostoria, Ont.	Crankshaft machining
Kendan Mfg.	Windsor, Ont.	Machining, high volume
Dominion Forge	Windsor, Ont.	Crankshaft forgings
PC Drop Forgings	Port Colborne, Ont.	Connecting rod forgings
Holmes Foundry	Sarnia, Ont.	Cylinder head castings
Crowe Foundry	Cambridge, Ont.	Gray iron castings
Kelsey-Hayes	Woodstock, Ont.	Gray iron castings
A. G. Anderson	London, Ont.	Prototype castings
Ingersol Machine	Ingersol, Ont.	Custom machining
Linamar Co.	Guelph, Ont.	N.C. machining
Galtaco	Galt, Ont.	Nod. & mall. iron castings
General Motors	Ste Catharines, Ont.	Iron castings, high volume

Table 2 POTENTIAL SUPPLIERS AND CONTRACTORS CONTACTED (Cont'd)

Name	Location	Product or Service
International Malleable	Guelph, Ont.	Nod. iron castings
Benn Iron Foundry	Wallaceburg, Ont.	Gray iron castings
Bata Engineering	Batawa, Ont.	N.C. machining
Accurate Crankshaft Grinding	Rexdale, Ont.	Crankshaft machining
Haley Industries	Haley, Ont.	Sand castings
Zollner Canada	Leamington, Ont.	Piston casting
Hardchrome Corp.	Toronto, Ont.	Crankshaft plating
Cyclo-Chrome Industries	Winnipeg, Man.	Crankshaft plating
Hastings Ltd.	Scarborough, Ont.	Piston rings
Thompson/TRW Canada	Ste Catharines, Ont.	Valves
Fel-Pro	Skokie, Ill.	Gaskets
Echlin	Hamden, Conn.	Ignition systems

5.0 TECHNICAL FEASIBILITY

5.1 Texaco Controlled Combustion System (TCCS) Principle

The basic concept of the TCCS allows initiation of combustion and control of its progress in the combustion chamber so that efficient energy conversion can be accomplished without the requirement for high octane or cetane fuel ratings.

Octane rating is an empirical engine test method that evaluates a gasoline's resistance to spontaneous ignition or "knock". Cetane is based on a different engine test, which determines a diesel fuel's ease of spontaneous ignition. High cetane number enhances cold starting and permits high-speed diesel engine operation. Further details concerning octane and cetane numbers are given in the literature referenced in Appendix A.

Utilizing a conventional piston-type engine with poppet valves located in the cylinder head, the Texaco process dictates that fuel shall be directly injected into the engine cylinder, mixed with air and ignited at the correct time to ensure efficient combustion.

The incoming charge is so directed during the intake stroke that it rotates (or "swirls") upon entering the cylinder. The air charge continues to spin during the compression stroke, at the end of which the air is forced into a small cup in the top of the piston. Entry into the cup causes the air rotational rate to increase, i.e. the angular momentum is conserved.

Figs. 2 and 3 illustrate the stages of combustion taking place in the piston cup. These simplified plan views of the combustion chamber show the coordinated arrangement of air swirl, high pressure fuel injection, and positive ignition. When combustion is to begin, near the end of the compression stroke, injection of the fuel into the swirling air is started and the mixture formed is ignited to establish a stationary flame front downstream from the fuel injection nozzle. As injection continues, additional mixture is formed and supplied to the flame front to be consumed at the rate at which it is formed.

Many characteristics of the DISC engine are direct consequences of the above concept. Initiating injection near the time for ignition eliminates the possibility of preignition (knock) regardless of the octane number of the fuel. The positive ignition feature eliminates any need for a fuel cetane number or the high compression ratio associated with the diesel engine. Also, it is evident that load control can be achieved by control of fuel quantity only, without the use of inlet air throttling. DISC engines thereby exhibit the good fuel economy of lean mixture engines.

The presence of the air swirl in the combustion chamber is one of the basic requirements for successful operation of the system, with the rate of swirl directly influencing the combustion duration and thereby the efficiency of the engine.

Experience has shown that although indicated thermal efficiency rises with increasing compression ratio, in reality the marginal improvements are small for ratios beyond approximately 12:1, as mechanical friction and other losses rise.

Extensive theoretical and practical work has established the optimum size and proportions of the cup for any particular operation. The cup has been idealized as having parallel sidewalls and a flat bottom, but this profile is by no means a constraining factor.

5.2 Engine Specific Factors

Application of the DISC principle to a specific engine design involves:

- Modification of the cylinder head to accommodate the required inlet port geometry, the fuel injection nozzle and relocated spark plug.
- Provision of the pertinent fuel injection system.
- Provision of the pertinent ignition device with appropriate timing.
- Modification of the pistons to accommodate the required cup profile.
- Modification of pertinent engine parts, as necessary, to accept the head, fuel injection system, ignition system, valve train and piston changes.

Thus each engine design involves its own set of modifications, and no single design solution exists that is applicable to more than one engine.

Fig. 2 AIR SWIRL, TIMED INJECTION AND IGNITION IN A TCCS ENGINE

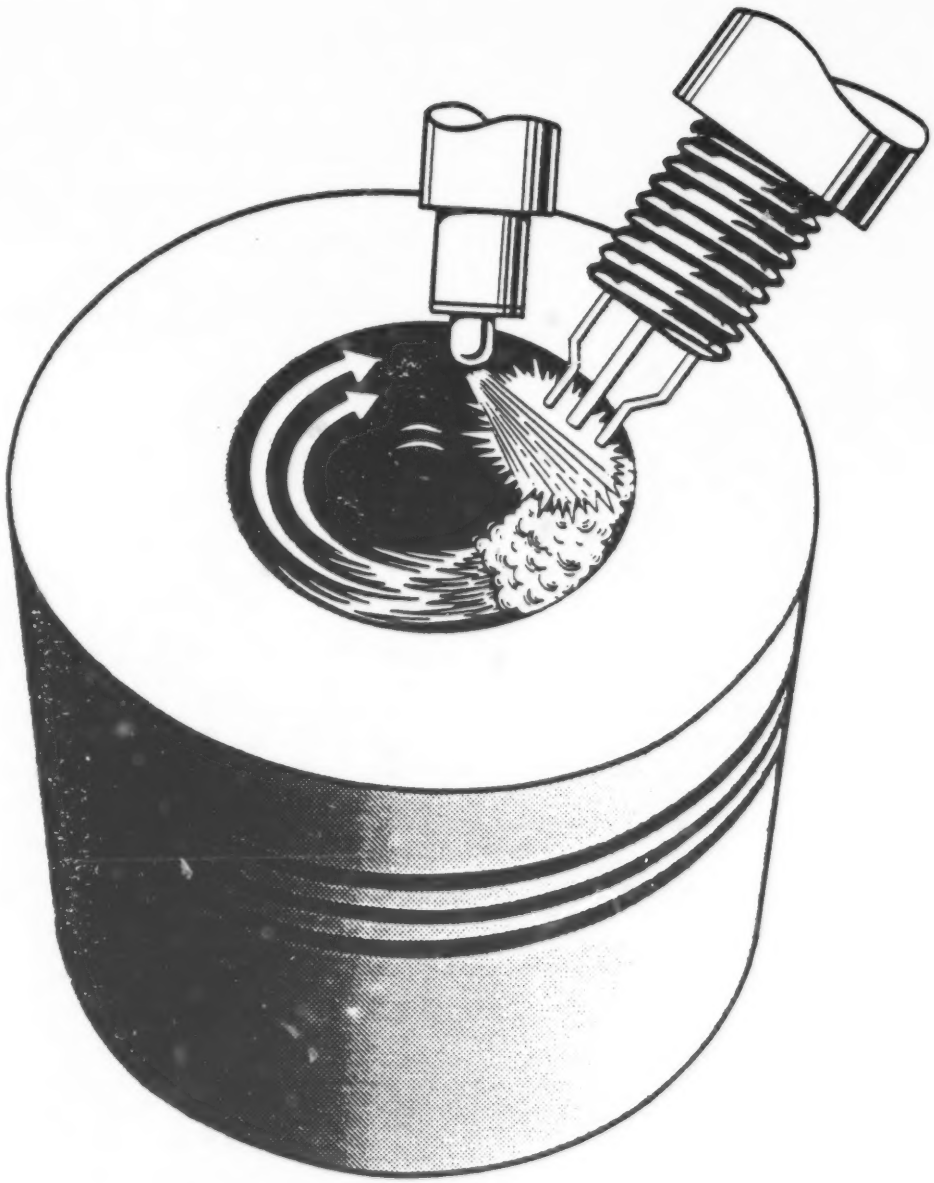
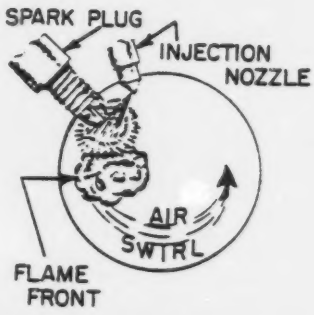
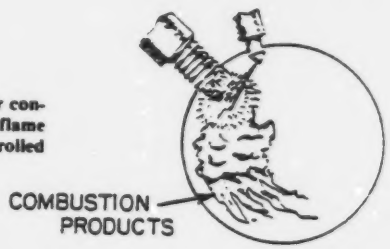


Fig. 3 **The Texaco Controlled Combustion System (TCCS)**

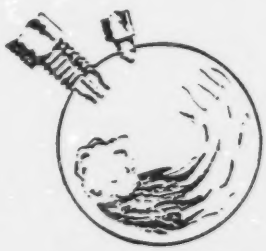


Air swirl, created by the intake port during the intake stroke, is intensified in a cupped piston design during the compression stroke. Combustion, initiated by fuel injection and positive spark ignition, establishes a flame front immediately downstream from the injection nozzle.

Spark continues; fuel is injected at a controlled rate; air continues to be supplied by the swirl to mix with fuel. The flame front is established and cylinder pressure builds at a controlled rate.



Spark is discontinued; fuel injection continues to mix fuel with air supplied by the swirl to feed the flame front.



Fuel injection is discontinued; flame front fades in intensity, but combustion continues until all fuel is consumed. The result is a clean burn of fuel in a lean mixture yielding low exhaust emissions.

5.3 Application of the DISC Principle to the Ford 300 Engine

External and internal views of the stock Ford 300 engine are shown in Figs. 4 and 5. The fundamental application of DISC technology to the engine was undertaken by Texaco Inc. to determine the basic design modification parameters. Thus for the 4.00" bore and 3.98" stroke of the Ford engine the location and form of inlet and exhaust ports, location of the spark plug, and location and orientation of the fuel injector were determined. Similarly, the shape of the piston crown profile and also the valve timing were determined by Texaco. The design evolved was based on a combination of theoretical studies and interpolation of existing empirical data derived from previous tests on a wide range of engine and component configurations.

These studies determined the changes that would be required to the existing cylinder head form to accommodate the revised inlet port geometry, relocated spark plug, fuel injector nozzle, revised combustion chamber profile and revised valve location. It was ascertained during the study that all of these geometric changes could be affected without necessitating changes to the engine block or head attachment bolts, with the exception of the push rod openings.

Study of the valving determined that the valve push rods would have to be realigned such that a potential interference would exist at the upper level of the block. This could be overcome by a single broaching operation of the block to enlarge the twelve push rod openings. The utilization of ball stud rockers to circumvent this rework was evaluated, but was discarded due to geometric complications. The required modification of the valve timing would be achieved by a simple replacement of the camshaft.

Replacement of the current carburetion system by a fuel injection system requires an additional timing drive, fuel pump and injection nozzles.

Maintenance of the spark throughout the duration of the fuel ignition pulse places more strigent requirements on the ignition system. Thus a new high energy ignition system is also required, being physically larger than the stock ignition system. These elements are shown in Figs. 6, 7, 8, and 9.

The engine bay of an Econoline van was checked for dimensions (see "Engine Compartment Dimensions" drawing) and it was determined that no packaging problems existed for the introduction of these items. External views of the converted Ford 300 engine appear in Fig. 10.

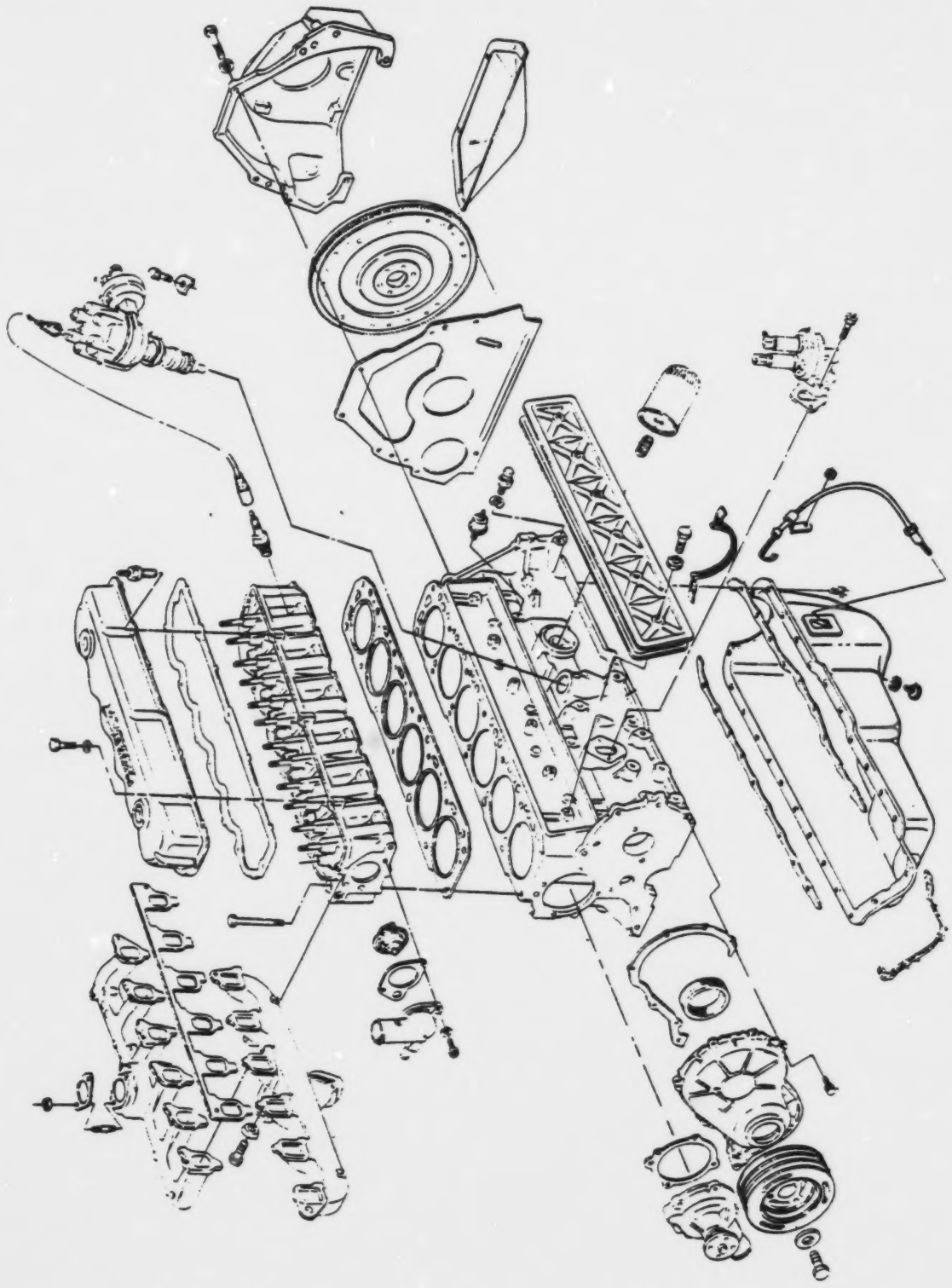


Fig. 4 EXTERNAL EXPLODED VIEW - FORD 300 ENGINE

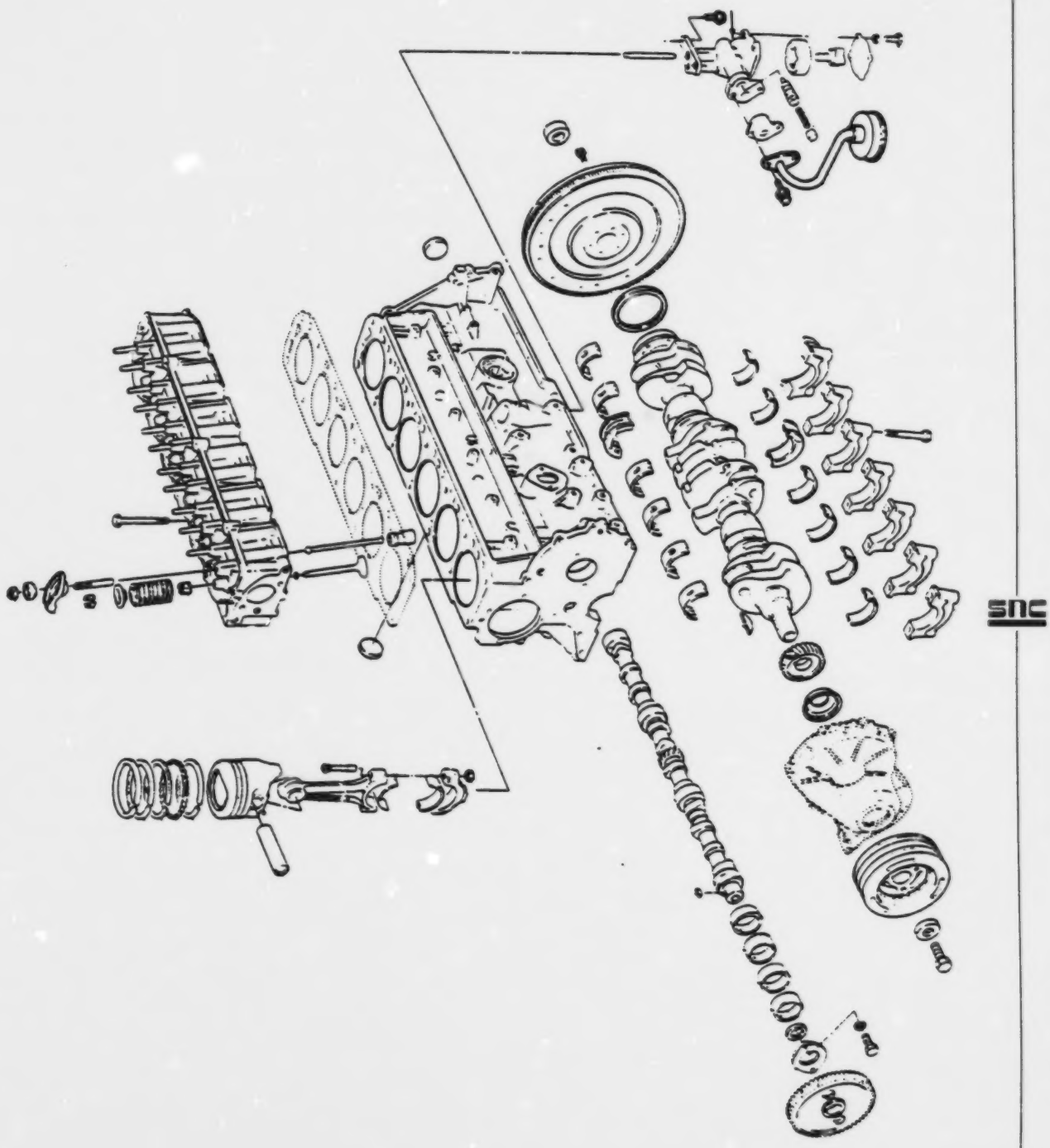


Fig. 5 INTERNAL EXPLODED VIEW - FORD 300 ENGINE

CONTROLLED-COMBUSTION SYSTEM ENGINE CONVERSION

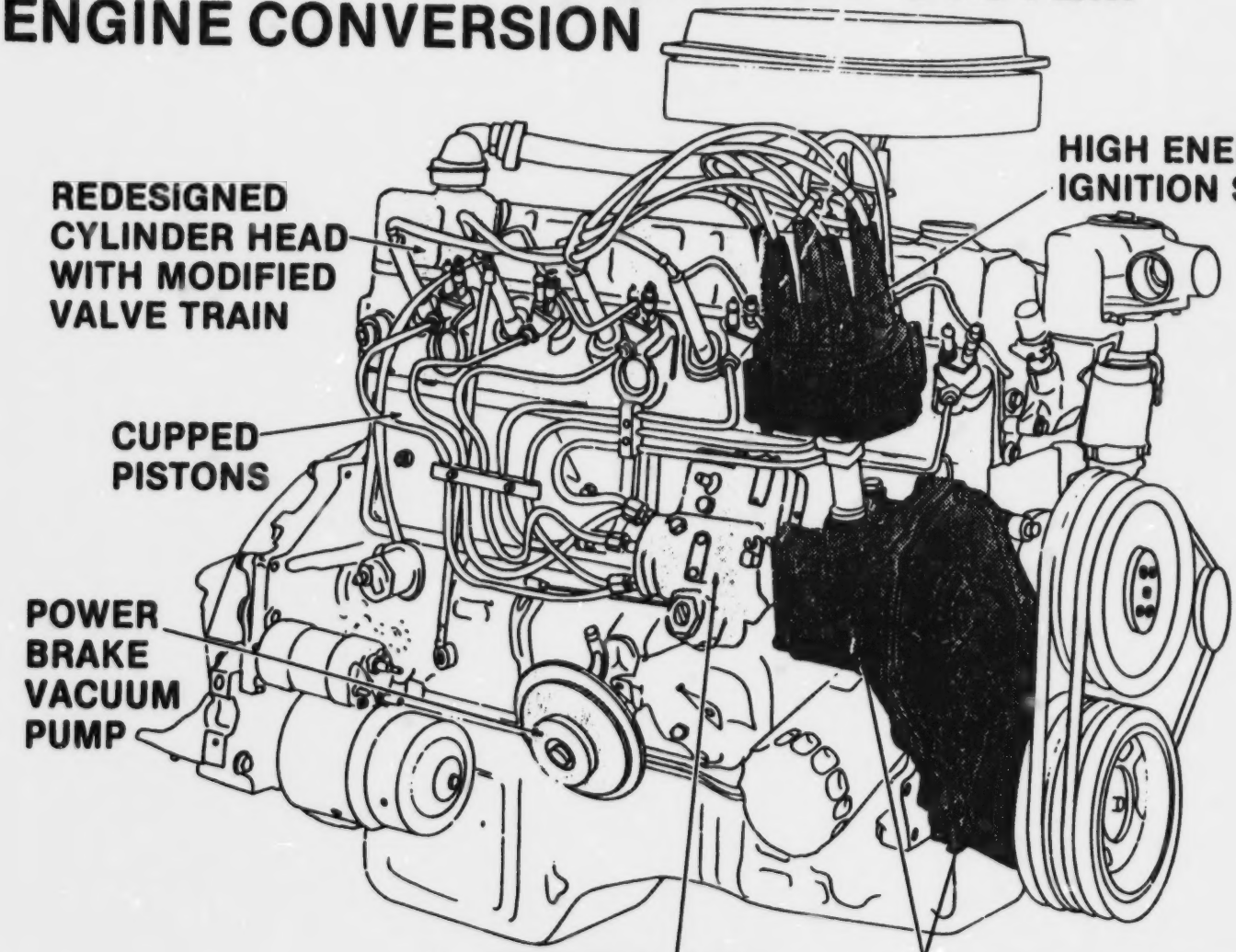


Fig. 6

Fig. 7

HIGH ENERGY IGNITION SYSTEM

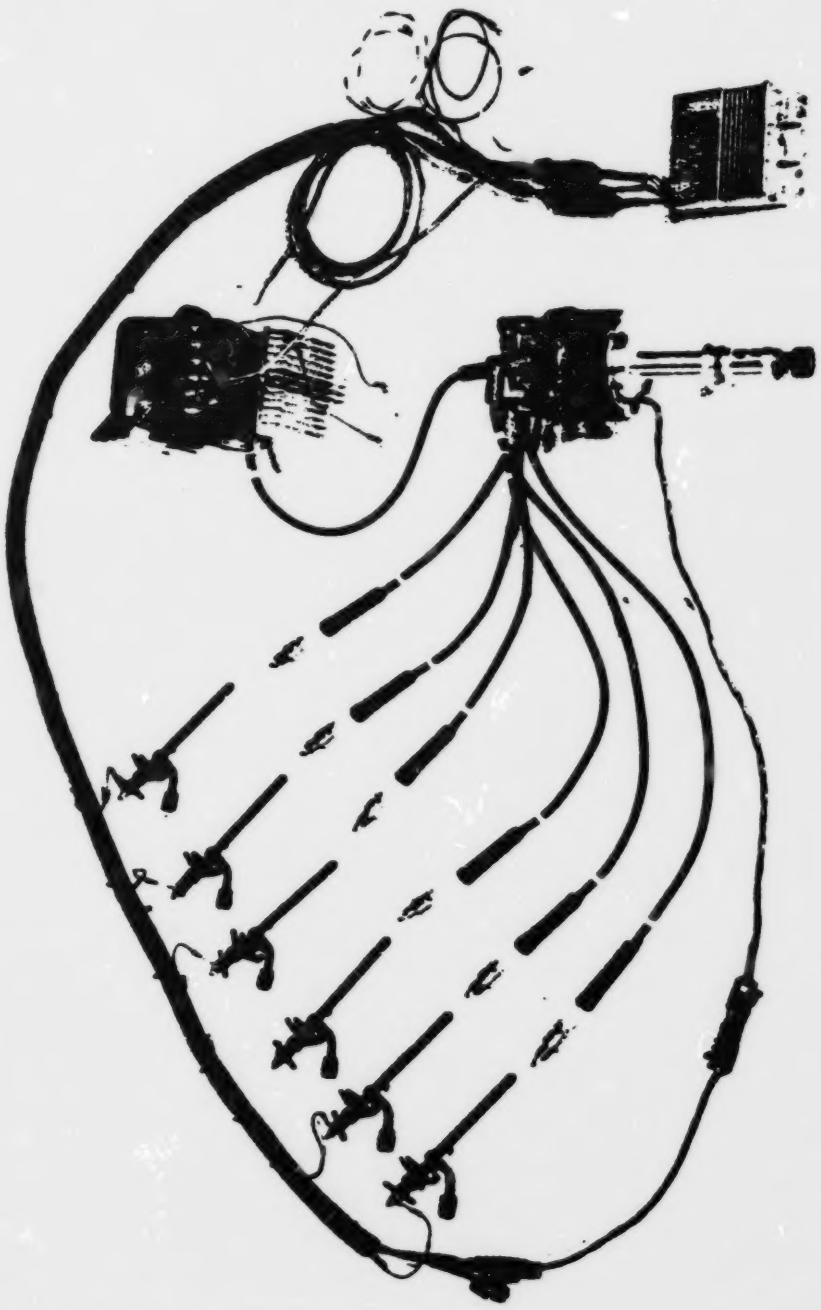
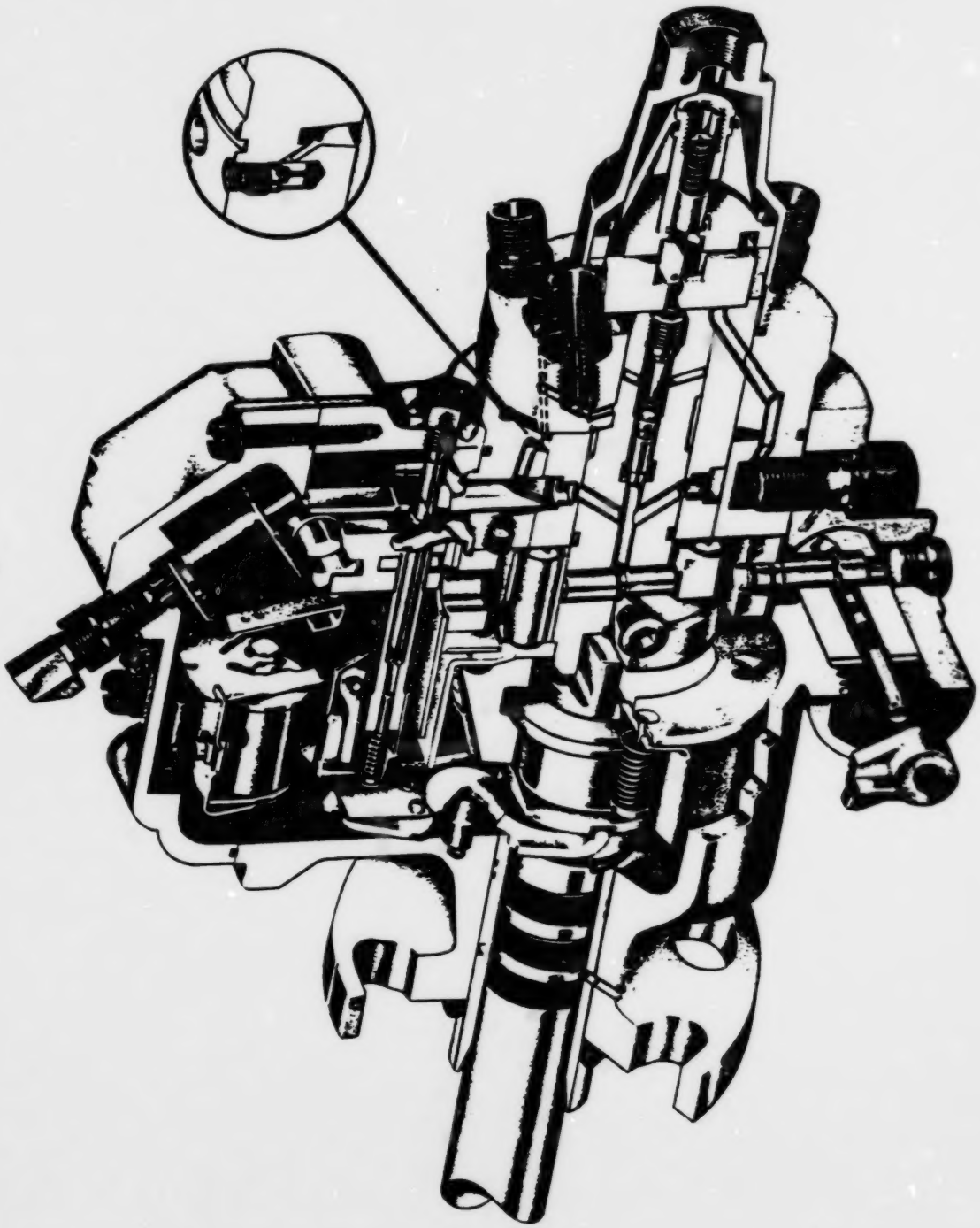


Fig. 8 MODEL DB2 AUTOMOTIVE PUMP



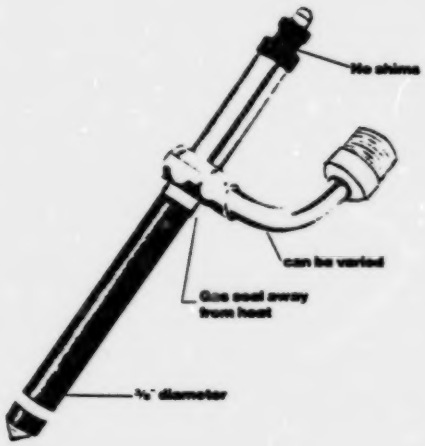
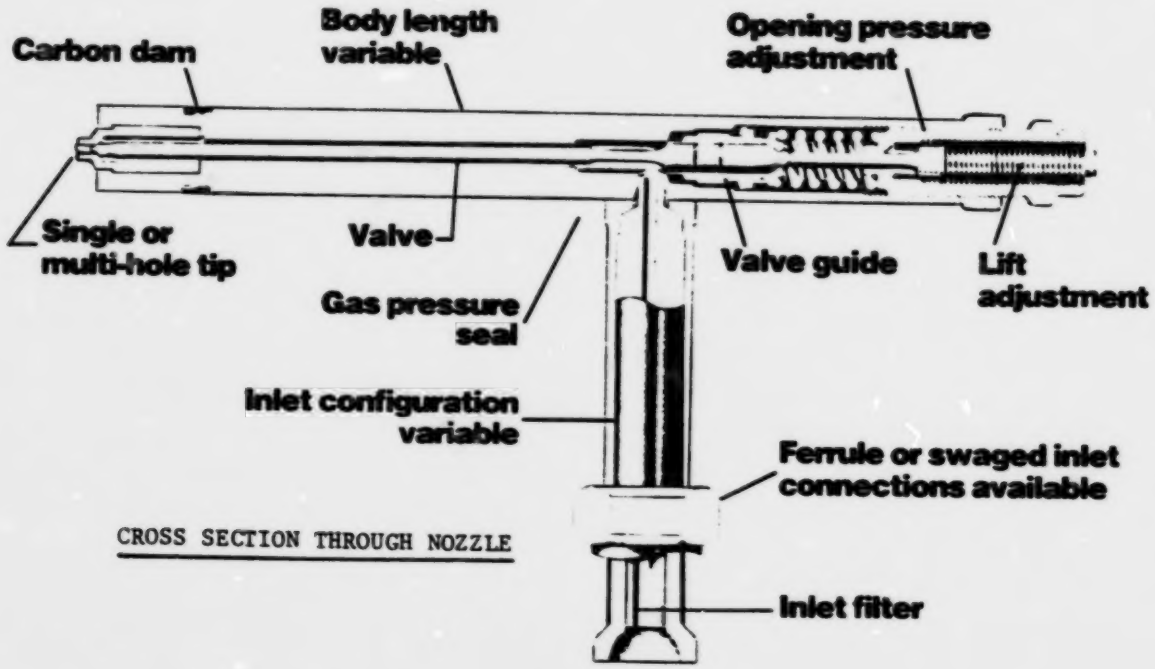


Fig. 9

Pencil Nozzle



CROSS SECTION THROUGH NOZZLE

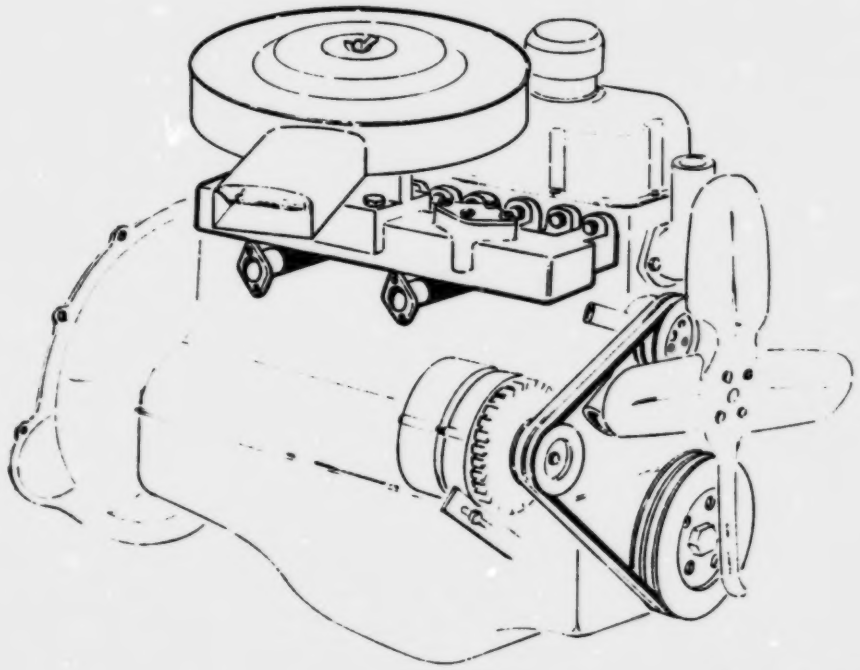
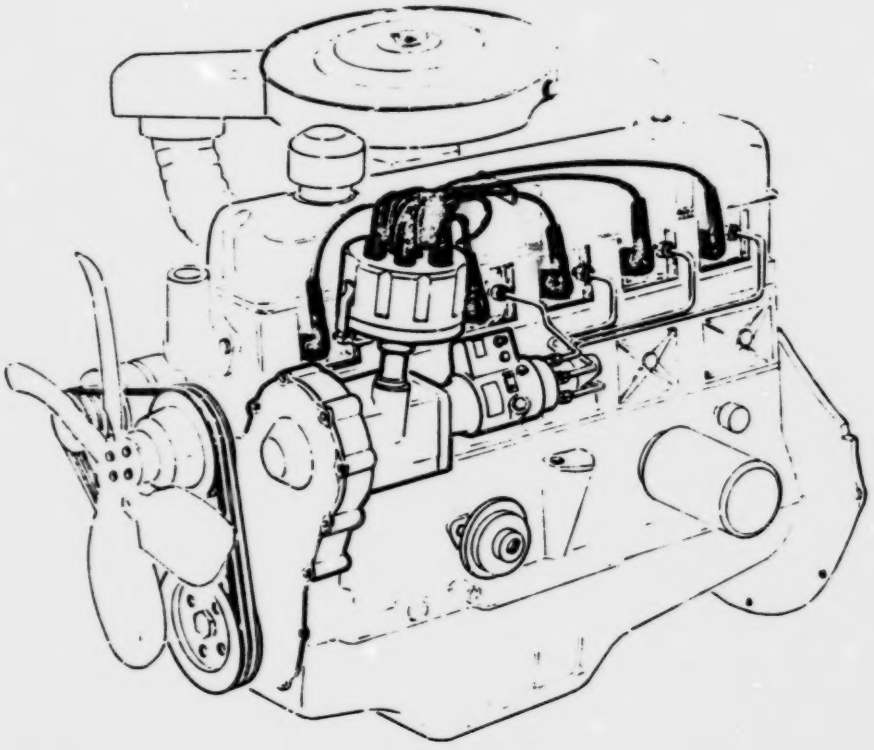


Fig. 10 EXTERNAL VIEWS OF CONVERTED FORD 300 ENGINE



Examination of the requirements for re-profiling of the piston crown, however, revealed a 'classic' engine design evolution problem, i.e. limited engine block height. The concept of cylinder charge high swirl angular velocity at piston top-dead-centre implies introduction of a cup having a specific shape in the piston crown. From a structural point of view, since the piston crown thickness and crown underside-to-wrist pin outside diameter distances are already close to minima, the required change in piston profile could only be achieved by raising the height of the piston crown outer annulus relative to the wrist pin centre-line, causing the piston crown to extend above the deck of the block at top-dead-centre. In the present instance the protrusion was 0.375".

Several direct design solutions were evaluated to overcome this situation, shown in the attached drawing 6427-0000-45DD-003 (see Appendix B) as Arrangements 1 through 4:

Arrangement 1

Conceptually, the cylinder head could be counter-bored to accommodate the increased piston height. While this could be done on a prototype engine basis, the dimensional accuracy required for competitive cost manufacturing to control the accumulation of tolerances from assembly to assembly, if custom fitting is to be avoided, are quite impractical.

Design constraints imposed by production line limitations are discussed in Appendix D.

Arrangement 2

The piston crown outside diameter could be locally reduced to clear the maximum possible accumulation of tolerances expected in mass production. To ensure clearance between piston and cylinder head counter-bore at one extreme would involve a substantial local piston radius reduction. Conversely, such a reduction combined with an extreme accumulation of tolerances of the head dimensions could result in an excessive radial gap, which would permit carbon build up, a "cold" corner with ultimately poor emission characteristics, and inadequate production line control of compression ratio.

Arrangement 3

The piston crown could be bevelled (or provided with some other appropriate contour) with a matching head profile. This would reduce the 'cold corner' problem, and minimize the tolerance accumulation problem.

However, a bevel of sufficient size, typically 0.375" at 45°, would impinge on the valve area, necessitating either relocation of the valves (extremely difficult), or special profiling of the valves (impractical).

Arrangement 4

The connecting rod could be shortened by 0.315" and wrist pin diameter reduced to 0.91". While this approach would solve the top-dead- centre problem, it would precipitate other problems:

a) At bottom-dead-centre the wrist pin centre-line and hence point of application of side loads would be below the cylinder bore in the block, resulting in galling of the piston sidewall

b) The ratio of connecting rod-length-to-crank throw radius, referred to as L/R ratio on the drawings, would be very low (less than 3:1) giving rise to high side loads, with potential for reduced engine life.

c) The required reduction in pin diameter from the stock 0.97" to 0.91" is extreme and would lead to excessive bending deflections in the pin, even if a solid pin were substituted.

With these direct approaches eliminated, alternative solutions were evaluated, shown attached as Arrangements 5 through 8 on drawing 6427-0000-45DD-004.

Arrangement 5

Introduction of a dry sleeve would increase the height of the bore face. In this approach the approximate proportions of the combustion chamber would be maintained, with only a slight reduction in actual bore, and some added support for the piston at bottom-dead-centre would be gained due to protrusion of the sleeve below the bottom of the bore. Block wall thickness and heat transfer requirements dictate a maximum limit on liner thickness at approximately 0.060", of which part must come from a counter bore in the block. Thus only small 'improvements' could be realized.

Arrangement 6

This illustration shows a 'shallower' piston cup, resulting in a higher compression ratio and consequent higher component stresses.

Arrangement 7

Use of a 'domed' piston cup to accommodate a standard crankshaft, new connecting rod and rod/throw ratio of 3:1 is another design solution.

The last two approaches (Arrangements 6 and 7) require special consideration with respect to state of the technology, and engine load capability.

Use of shallower cup per Arrangement 6 would involve performance and design penalties. If the cup diameter were maintained, the compression ratio would rise. A compression ratio of 17:1 would be required to achieve the dimensions sought. This would involve a performance penalty, i.e. experience has shown that the compression ratio is too high and the efficiency would be off-design. Furthermore, the stress levels in the engine would be unacceptably high. Conversely, maintenance of the cup volume (and hence compression ratio) would lead to an excessive cup diameter and hence inadequate swirl at top-dead- centre.

The geometry of the cup illustrated in Arrangement 7 is such that a shallow axi-symmetric "dome" is provided to clear the connecting rod at the wrist pin. The wrist pin bearings would be housed in bosses designed so that the 'dome' would be profiled about a vertical axis of symmetry, without sacrificing structural adequacy, and the thickness of the cup bottom (the dome) could be reduced to take advantage of the preferential structural form.

For the 'normal' flat based cup bottom, the stress criteria are the combined peak gas pressure, inertial load, and thermal gradient occurring nominally at top-dead-centre. While detail stress analyses are possible, these presume accurately known loads. At the existing state of evolution of the engine design, a 'rule-of-thumb' thickness allowance, based on documented experience with piston design and operation was judged to be sufficiently accurate.

Thus, from a structural aspect, this design is feasible, and would conserve the cup volumetric capacity, maintain cup diameter: depth ratio, and would allow the required reduction of wrist pin centre line-to-piston crown height to permit retaining the standard crankshaft.

However, the swirl characteristics would undoubtedly be affected by the proposed new profile-possibly beneficially.

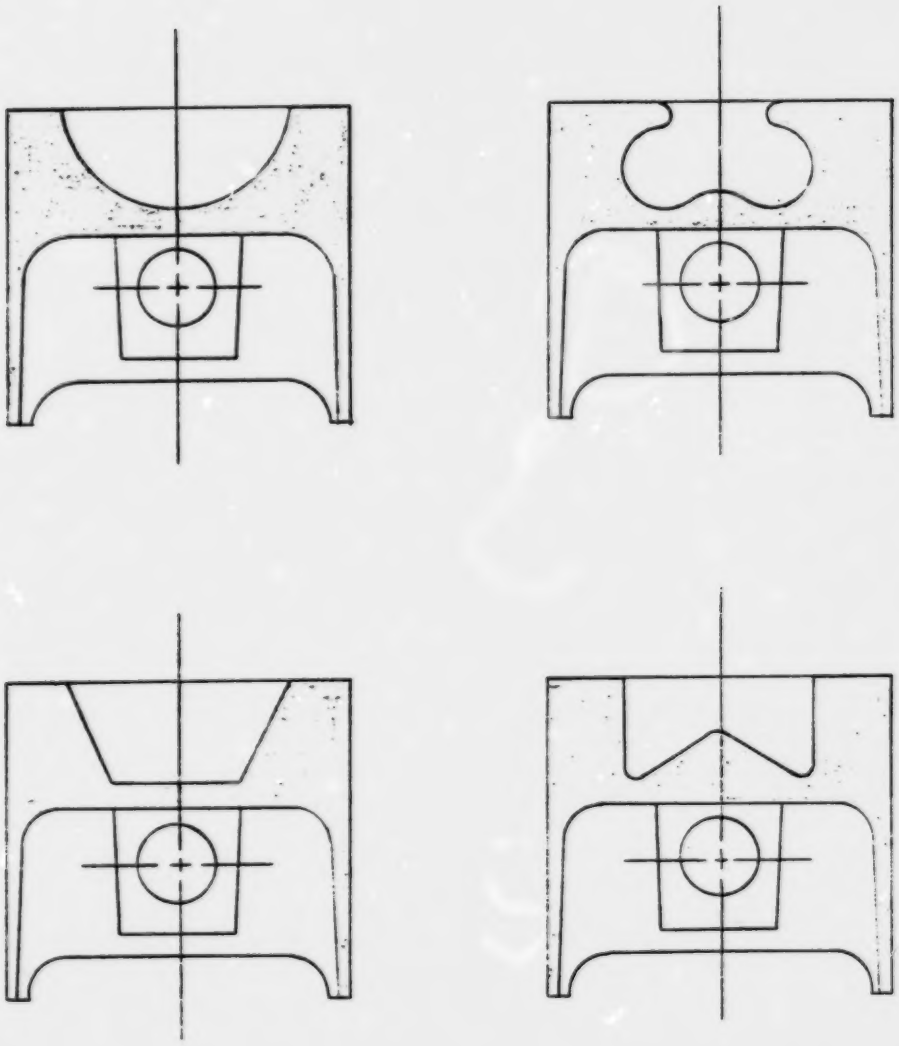


Fig. 11 Alternative Piston Cup Profiles

Texaco (and others) have studied and experimented with a large number of 'cup in piston' designs. The profile of the cup base has taken many forms either to facilitate manufacture or to conform to some theoretical criteria of pressure distribution, velocity distribution or maintenance of angular velocity. Some sample profiles are given in Fig. 11. Accordingly, there is reason to belive that the 'dome' profile would be viable, though appropriate analysis and testing would have to be done.

Arrangement 8

This solution involves modification of the crankshaft to reduce the throw radius, combined with a new connecting rod. This arrangement has the merit of utilizing proven technology, offset against the cost of a new crankshaft design and a small (5%) reduction in engine displacement with a corresponding drop in engine power output. This slight reduction in output, in the opinion of Purolator Courier Ltd. and other fleet operators, will not affect vehicle operation in suburban service.

A new reduced-throw crankshaft, however, would be costly in terms of design, development, and tooling requirements, in addition to the unit cost of manufacture. Several approaches were evaluated in an effort to reduce the cost penalty, including:

1. Modify existing crankshafts by eccentrically grinding the crankpins, followed by rebalancing and hardening of the journals. This procedure could be satisfactory for small changes in throw radius for experimental work, but is not judged to be sufficiently reliable for volume remanufacture.

2. Intercept production of present crankshafts at an intermediate stage of the current forging process, and produce the required volume having the desired throw radius. Fewer forging dies would be needed using this technique, resulting in lower tooling costs. The possibility of re-forging existing crankshafts was considered, but its feasibility was not proven.

3. Machine crankshafts from solid steel billets. This approach would allow complete redesign freedom and component reliability, with low design and tooling costs. It is the method normally used in the industry for producing prototype engine crankshafts, and a number of firms specialize in crankshaft production using the technique. Unit production cost is high however, rendering it unsuitable for volume manufacture.

As indicated in the next section (paragraph 5.4.4) Arrangements 7 and 8 were selected for preliminary engine design work.

As a result of these studies of engine layouts and fundamental geometries, a preliminary engine design was developed to serve as the basis for further design work. The design description, together with equipment and tooling lists, are contained in the following section of this report.

5.4 Preliminary Design

5.4.1 General

Overall engine design considerations included the following:

1. Design of engine for broad fuel tolerance, including alcohols. Initial engine mechanical development would be done on gasoline, followed by an "alternate" fuels development program.

2. Design of converted DISC engine to permit convenient installation in Ford light trucks and a variety of other vehicles.

3. Design of engine to permit future upgrading using turbocharger.

4. Utilization of engine components that will remain readily available, standard automotive hardware, regardless of manufacturer.

5. Design of cylinder head to accommodate present and future requirements for temperature, pressure and oil sensors for emissions and maintenance monitoring functions.

6. Design of engine incorporating Basic Design Requirements and Vehicle Requirements listed in Tables 3 and 4.

5.4.2 Cylinder Head and Valve Train

A new cylinder head would be required for conversion of the Ford 300 engine to DISC technology, complete with new inlet and exhaust manifolds, air filter and valve rocker arm cover. Cylinder head geometry recommended by Texaco is shown on attached drawings CS-D-6110, and CS-D-6116 (see Appendix B). The new head, produced in gray cast iron, would utilize the standard head bolt and push rod locations, and would register with existing block cooling water and lubrication oil passages. Small recesses may have to be drilled on the engine block to permit adequate pushrod clearance; otherwise no block modifications are anticipated. Notable cylinder head features include the use of discrete, swirl-generating inlet ports; flat head/block mating face with minimum cylinder clearance volume at piston top-dead-center; vertical, parallel valves; roller bearing rocker arms and hydraulic camshaft followers.

A new camshaft would be required, profiled to yield rapid valve opening with minimum overlap.

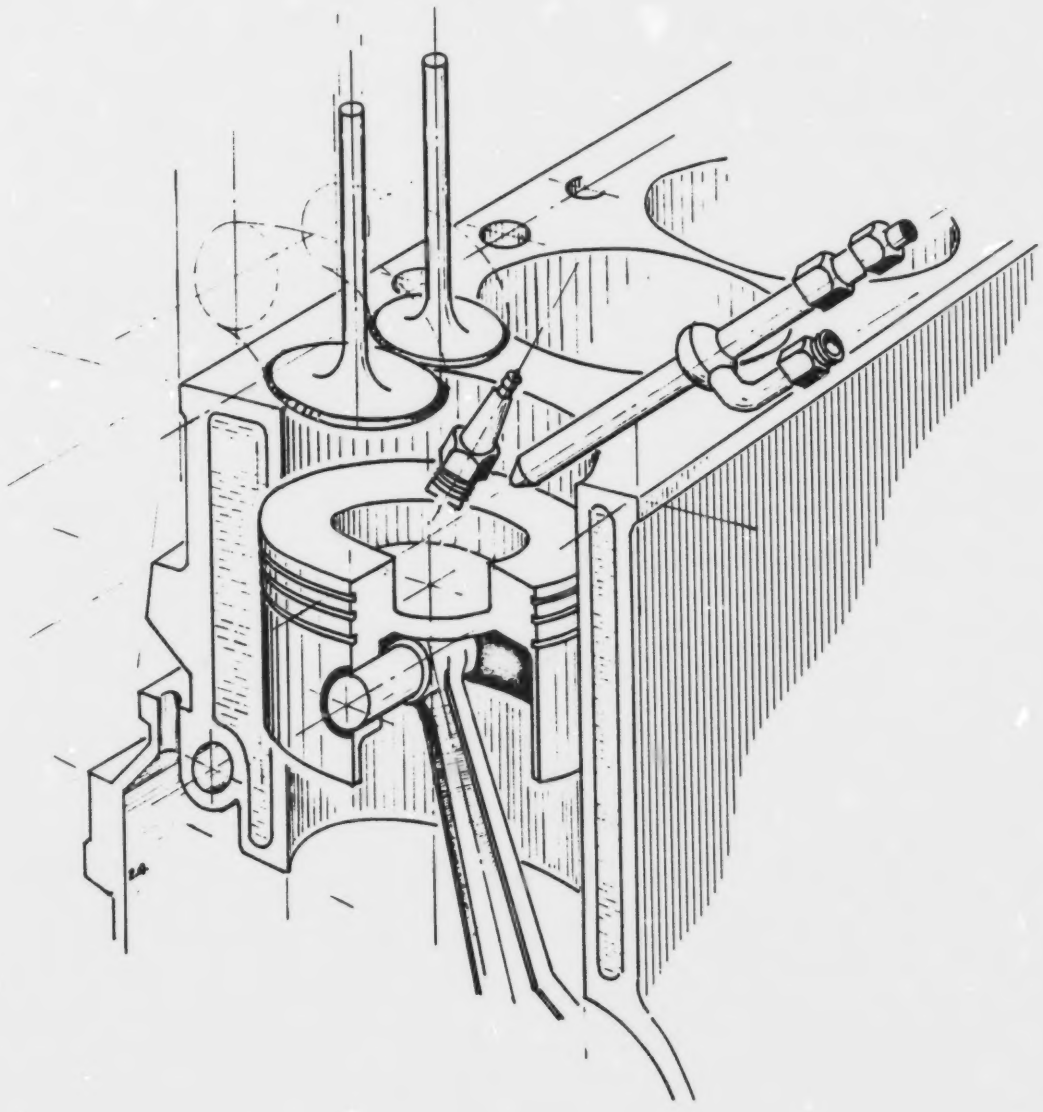


FIG. 12 DISC ENGINE COMBUSTION CHAMBER ARRANGEMENT

5.4.3 Fuel Injection and Ignition Systems

As illustrated in Fig. 12 one fuel injector and one spark plug are used for each cylinder, positioned so that fuel sprayed under high pressure impinges directly on the spark plug, resulting in a long duration, positive ignition of the fuel/air charge. Nozzles recommended are pencil-type and easily removeable, with high pressure fuel supply coming from a central, mechanical pump running at half engine speed and driven by a special gearset replacing the stock distributor drive arrangement. A fuel pump featuring external lubrication and electronic controls is recommended.

Positive ignition would be provided by a special high energy system firing special multiple-ground electrode spark plugs. Electronic circuitry would be necessary to satisfy the precise control and large power requirements of the high voltage secondary circuit. Spark timing would be linked to the fuel spray sequence via nozzle signal triggering or similar means.

Radio frequency noise suppression equipment may be required to overcome any potential broadcast interference generation.

5.4.4 Piston and Crankshaft

Replacement of the stock crankshaft with a new forged steel unit having a reduced throw radius, as shown in Arrangement 8 on dwg. 6427-0000-45DD-0004, represents the design solution to the block height restriction having the least requirement for further detail design or potential for development problems. The additional design, development and manufacturing costs associated with a new crankshaft are significant and cannot be ignored, however.

The 'domed' piston cup configuration (Arrangement 7), incorporated into a forged aluminum alloy piston, offers the economic advantage of retaining the stock crankshaft. This advantage may or may not be offset by the increased design and development costs related to the unusually compact piston cross section.

A program of further evaluation of the merits of both Arrangements 7 and 8 is beyond the scope of this study, and would be required before a recommendation could be made on the selection of piston and crankshaft geometry.

5.4.5 Accessories

In addition to the special gear drive required for the distributor and fuel pump, a vacuum pump would also be required to provide power brake boost, since the DISC engine is unthrottled and thus does not generate inlet manifold vacuum. A commercially available vacuum pump as developed for diesel engine use is recommended, driven by a suitable take-off from the camshaft, fuel pump drive shaft or crankshaft.

Improved engine temperature control is also recommended, achieved by revised coolant flow circuitry and installation of a revised thermostat. The unthrottled nature of the DISC engine results in reduced heat rejection to the engine coolant under partial load conditions, providing less driver compartment heat and longer engine warm-up time. This cooling improvement would restore cooling system performance to levels attained in unconverted Ford 300 engines.

A complete list of new equipment requirements is contained in the attached Table 5.

5.5 Tooling Requirements

The various patterns and dies required for prototype engine construction, as well as the tooling requirements for the Canadian engine manufactured in volume, are listed in Table 6.

Prototype tooling is far lower in cost than production quality tooling, and is built in a manner to facilitate rapid changes in design as found necessary during early testing. Consequently, prototype tooling is useful for production runs of only a small number of engine parts, typically limited to lots of less than 100 items.

Industry practice dictates that production tooling is purchased from the supplier separately from the component produced, i.e. each manufactured part bears a unit cost in addition to an initial tooling charge. Ownership of the tooling remains in the hands of the supplier for exclusive use by the purchaser.

Canadian suppliers were contacted regarding their experience with production tooling. It was established that the capability exists to satisfy all of the DISC engine tooling and manufacturing requirements using existing Canadian sources.

TABLE 3 ENGINE BASIC DESIGN REQUIREMENTS

Cylinder Head Geometry	Refer to engine dwgs. CS - D - 6110 CS - D - 6116
Piston/Crankshaft Geometry	Refer to Piston/Crankshaft Arrangement drawings. Design to incorporate maximum of available components to reduce development time and cost.
Cylinder pressure	1000 psi (max.)
Cylinder pressure rise rate	60 psi (max.) per crankangle degree
Engine speed	3000 RPM (max.)
Compression ratio	12.0 (approx.)
Ratio of cylinder bore to piston cup diameter	2.0 (min.)
Ratio of connecting rod length to crankshaft throw radius(L/R)	3.1 approx. (min.)
Piston pin diameter	0.97" (min.) per stock Ford 300 engine
Protrusion of piston pin from bottom of cylinder bore at BDC	Pin diameter x 0.25 (max.)
Wall thickness of flat base piston cup	0.25" (min.)
Ignition system Requirements	Timing triggered by fuel injector nozzles. Continuous spark, duration 20 - 40 degrees crankshaft travel. Radio frequency interference to be minimized. Reliable operation under cold ambient and road salt conditions.

TABLE 3 ENGINE BASIC DESIGN REQUIREMENTS (Cont'd)

Fuel System Requirements	Operation on gasoline, diesel oil and two intermediate broad-cut fuels. Operation on methanol and ethanol with system modifications (to be defined). Reliable starting under cold ambient conditions.

TABLE 4 VEHICLE REQUIREMENTS

The following vehicle requirements were developed in consultation with Purolator Courier Ltd., fleet operators of Econoline delivery vans, based on their experience with the Ford 300 engine:

Test Vehicle	Ford Econoline Van
Vehicle GVW, max.	7000 lb.
Peak payload	1800 lb.
Driving cycle, Eastern Canada mileage	35% urban 65% highway
HP required, approx.	100
RPM, max.	3000
Transmission type	Automatic, 3-speed
Cold start temperature, min.	-20°F
Engine oil and filter change interval	8000 mi.
Engine minor tuneup interval	16,000 mi.
Engine overhaul interval	120,000 mi.

TABLE 5 NEW PRODUCTION ITEMS REQUIRED FOR DISC RETROFIT KIT

Qty	Description or	Tooling Req'd (T) Stock item (S)	Material Category
1	Crankshaft	T	forged steel
6	Connecting rods	T	forged steel
6	Pistons	T	forged aluminum
6 sets	Piston rings	S	cast steel
1	Cylinder head	T	cast iron
2	Exhaust manifolds	T	cast iron
2	Intake manifolds	T	cast iron
1	Camshaft	T	cast iron
1	Valve cover	T	cast aluminum
1	Injection pump drive housing	T	cast aluminum
1 set	Misc. brackets and cover plates	T, S	stamped steel
1	Ignition system	S	-
1	Valve train	S	-
1	Vacuum pump	S	-
1	Fuel injection system incl. pump drive	S, T	-
1 set	Air and fuel filters incl. housing	S	-
1	Thermostat and cooling system modifications	S, T	-
1 set	Gaskets	S	-

TABLE 6 MAJOR TOOLING REQUIRED (exclusive of machining fixtures)

Item	Tooling	Prototype	Production
Pistons (forging)	Forging dies	X	X
Crankshaft (forging)	Hammer dies Restrike dies Trimmer dies Twister dies		X
Connecting rods (forging)	Hammer dies Trimmer dies Coining dies		X
Brackets Cover plates (stamping)	Stamping dies		X
Cylinder head (casting)	Cope and drag patterns Various coreboxes	X	X
Intake manifold	Cope and drag patterns		X
Exhaust manifold	Coreboxes		X
Valve cover			X
Injection pump drive housing			X
Camshaft			X
Thermostat housing			X

6.0 ECONOMIC FEASIBILITY

6.1 User Potential

In vehicle service, the DISC engine would gain the greatest market acceptance in the domain of light truck low-speed (urban) operation, because of the predominance of contemporary light vehicles using spark-ignited engines operating on gasoline (and lately, propane). These engines suffer great pumping losses due to inlet throttling, resulting from their high idling times and mainly low vehicle speed operation. The DISC engine is better suited to this type of vehicle market, for a variety of reasons outlined earlier in this report, and has a particular advantage over diesel powerplants in terms of ease of vehicle retrofit conversion.

6.1.1 Retrofit Potential

The possibility of convenient DISC retrofit is the subject of great interest on the part of light truck fleet operators, judging by the number of inquiries received by Texaco in the Unites States from major fleet users (refer to Table 7).

A brief survey of DISC potential among fleet users of delivery vans in Canada conducted as part of this study produced a parallel positive response, a summary of which is displayed in Table 8). An important finding of this survey is the fact that big delivery fleet operators tend to rebuild engines several times at intervals ranging from 80,000 to 120,000 miles over the life of the vehicle, making them ideal candidates for retrofitting DISC engines in large numbers.

Major fleet users in Canada of the Ford 300 engine include the firms identified in Table 9. Twenty-two firms are listed, of which five were contacted as a representative sample and interviewed during this study. These firms were surveyed not only for their own experience but also their knowledge of general industry practices. Assumptions stated in this section were based upon survey data.

The retrofit potential overall market size for Canadian trucks having Ford 300 engines has been estimated for each calendar year until 1986, with the results illustrated in Fig. 13. Average annual retrofit potential in Canada is approximately 15,000 vehicles, assuming that the average vehicle life is 7 years and that 50% of the vehicles' engines are rebuilt after 4 years of service. The United States potential (Fig. 14), also based on historical sales figures, is 10 times greater at 150,000 vehicles per year, with average fleet size being larger than the Canadian counterpart.

6.1.2 Original Equipment Sales Potential

Data supplied by Ford has been used to prepare Fig. 15, which shows the relationship between potential market share and price premium for light truck original equipment options offering a range of fuel mileage improvements over a suburban (mixed) driving cycle. It should be noted that the data applies to the price sensitive market only, excluding those buyers who buy on the lowest first cost basis regardless of operating costs. So also no credit has been allocated for secondary benefits such as reduced maintenance, better cold weather performance, or multifuel capability.

For operation on gasoline, Fig. 15 indicates that a small segment of the original equipment light truck market could be captured based on the projected cost premium of US $2000 to US $3000 for a DISC engine. The increased fuel mileage when operating on diesel or other broad-based fuels would allow a much greater market penetration, to the extent that such a DISC engine package would sucessfully compete with original equipment diesel and propane engine installations for their respective market shares.

Fig. 13 CANADA MARKET RETROFIT POTENTIAL
FORD 6 CYL. TRUCKS

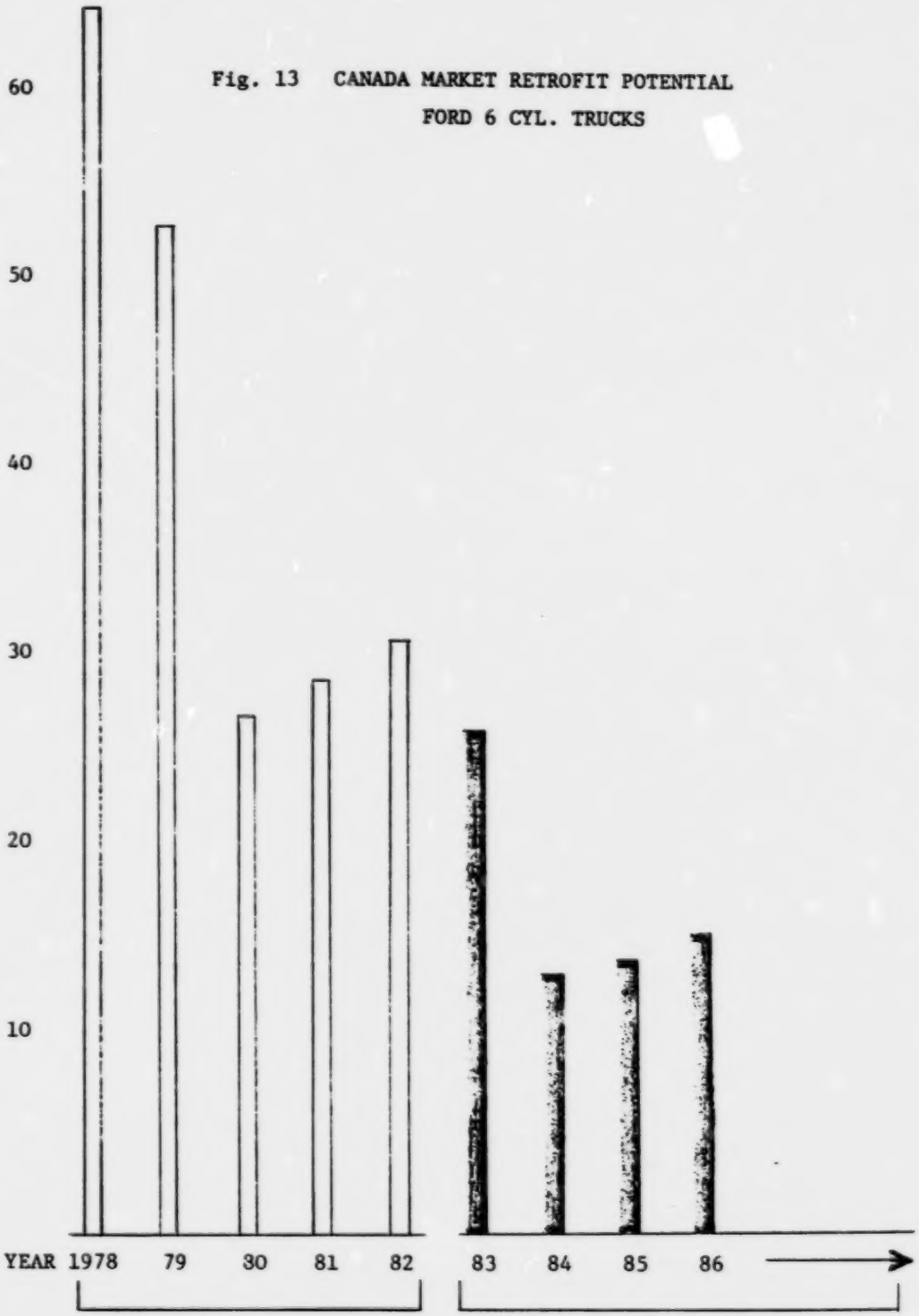


Fig. 14 U.S.A. MARKET RETROFIT POTENTIAL
FORD 6 CYL. TRUCKS

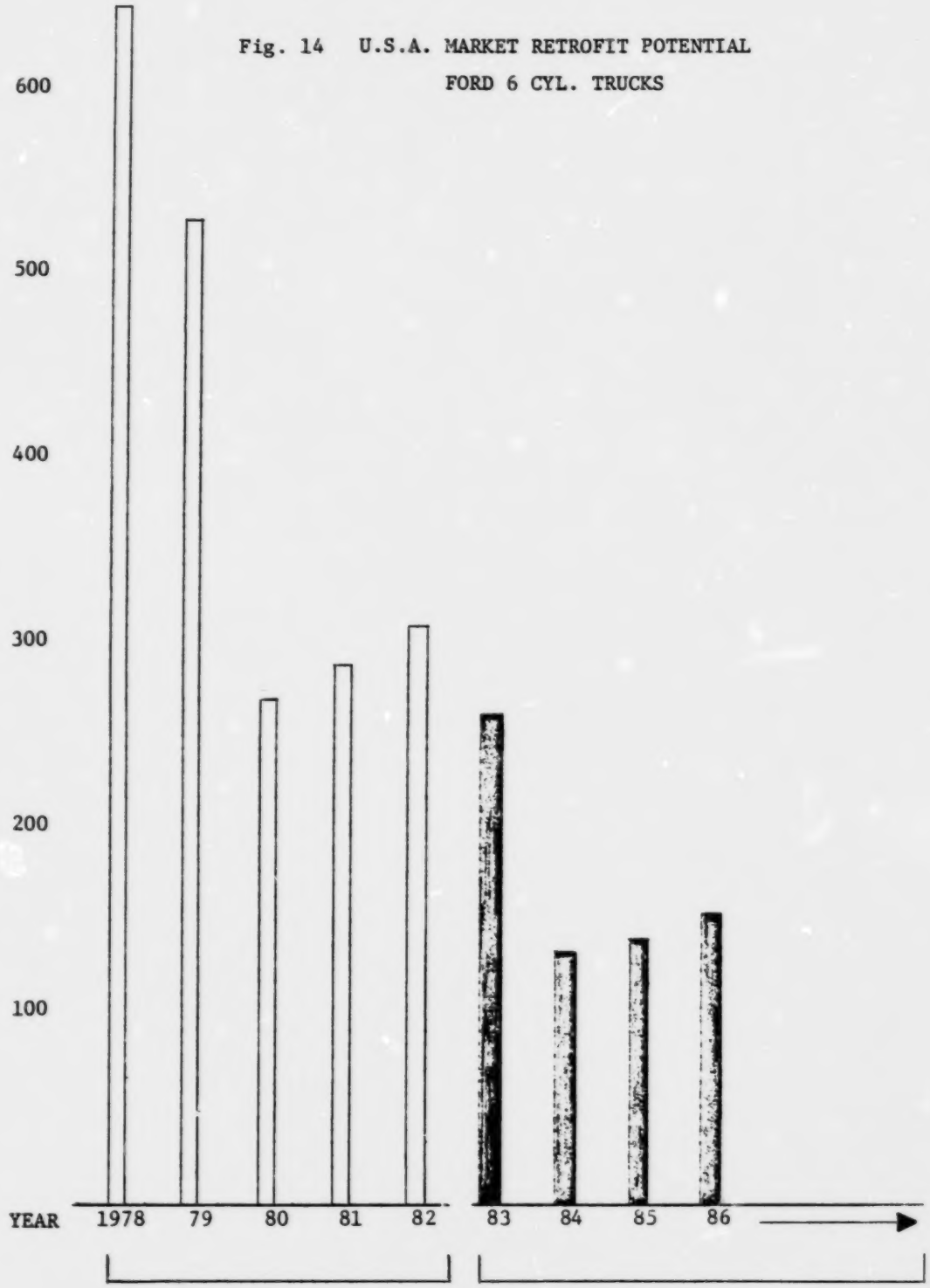
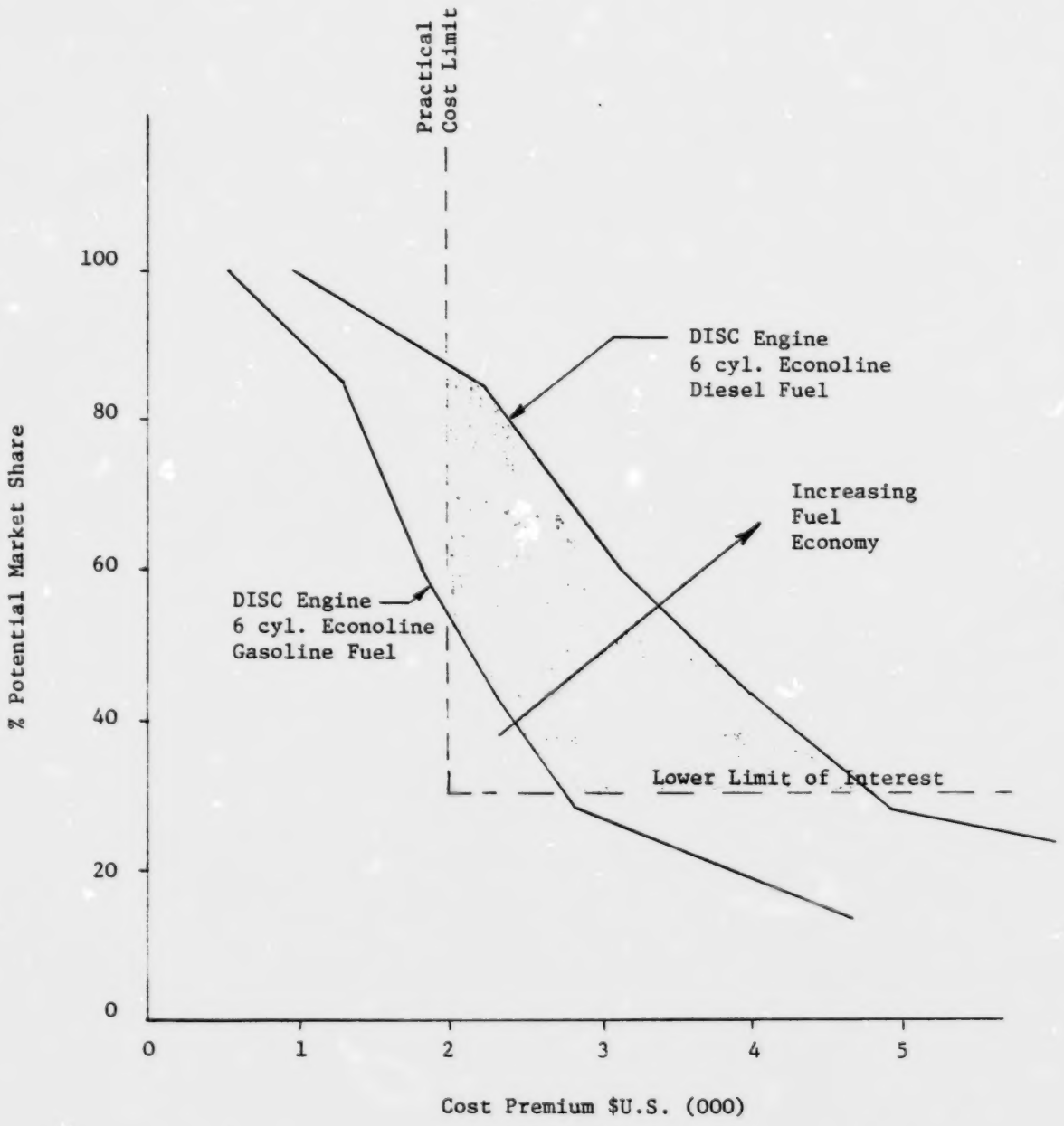


Fig. 15 MARKET SHARE vs COST PREMIUM



Based on: - price sensitive market segment
- 2 yr. payback period
- mixed driving cycle (60% urban)
(40% highway mileage)

TABLE 7 MAJOR FLEET OPERATORS WHO HAVE CONTACTED TEXACO RE TCCS ENGINE

Norton Air Force Base - Study of base support vehicles converted operate on jet fuel rather than having to supply gasoline to bases - 30-40,000 vehicles

U-Haul - 9,000 Ford trucks with Ford 300 HD engines

Blessings Diaper Supply Co.

Coca-Cola - 5,000 trucks

Minneapolis Public Schools

Truck Leasing Companies - several small ones

Entemanns Bakeries - 12,000 delivery vans

Watkins Truck Leasing

GAF Corp.

ITEL

Rentnal

National Truck Rental

EM Thorp Truck

Delco Fleet Leasing

General Services Admin. (U.S. Govt)

Ryder Truck Rental

Frito-Lay

TABLE 8 RANDOM SAMPLING OF FLEETS USING VANS

Potential Fleet User	Total Fleet Vehicles	Number Equipped with Ford 300	Rebuild or trade Policy
Gazette	40 - Montréal	40	Trade
B.D.C.	115 - Montréal	0	Trade
Bell Canada	3500 - Québec	Unknown	Rebuild
Federal Express	40 - Canada	40	Rebuild
	4000 - U.S.A.	2000	Rebuild
Kourier	90 - Ontario & Québec	0	Trade
Purolator	900 - Ontario & Québec	900	Rebuild
Loomis	Unknown	0	Unknown
Post Canada	1000 - Canada	200	Rebuild

TABLE 9 CANADIAN FLEET OPERATORS USING FORD 300 ENGINE

The following operators were contacted regarding their fleet operation practices and interest in DISC technology:

Purolator
Gazette
Bell Canada
Federal Express
Post Canada

The following Ford 300 fleet operators were not contacted:

United Parcel Service
Sears
Province o Saskatchewan
City of Calgary
Govt. of Ontario
Air Canada
McLean-Hunter
Ontario Hydro
CIP
Govt. of Québec
Camco Leasing
Great Lakes Forest Products
Imperial Oil
City of Edmonton
Petro Canada
Dow Chemical
Cominco

6.2 Preliminary Economic Analysis

6.2.1 Energy Savings

Fuel savings attributable to a DISC engine installed in a typical delivery vehicle are shown in Table 10 for operation on both gasoline and diesel fuel. The data have been developed for a mixed urban/highway driving cycle from information supplied by Ford, Texaco and comparative data obtained from EPA test results.

Operating on gasoline, a typical suburban delivery van or pickup truck equipped with a DISC engine would save 400 US gallons of fuel annually, travelling 20,000 miles during that period. Due to its greater volumetric thermal content, the fuel savings when operating with diesel fuel under the same conditions would be 600 US gallons annually per vehicle.

For the case of a fleet size of 1000 vehicles, a total fleet savings of 86,000 barrels of diesel oil would be accrued, based on average engine lifetimes corresponding to 120,000 miles.

In addition to the obvious economic advantages gained by individual fleet operators, the DISC program has the potential for significant contribution to the National Energy Program objectives, specifically, a substantial reduction in the quantity of oil imported for vehicle use. Savings can be realized through the use of broad boiling range fuel, which permits increases in efficiency of refinery operation, and through introduction of methanol, thereby displacing petroleum-based fuels.

6.2.2 Retrofit Cost Effectiveness

Fleet operators surveyed during the course of this study generally insist that the cost premium for equipment yielding better fuel performance shall be recovered within two years of operation, unless other advantages are evident, e.g., reduced maintenance costs. Market surveys of customer preference conducted by Ford Motor Co. based on original equipment sales have established a similar two-year payback period criterion.

Based on advantageous fuel costs of US $1.50 per US gallon presently enjoyed by fleet operators, Table 10 indicates potential annual diesel fuel savings of US $900 per fleet vehicle, which as a consequence dictates that the additional equipment cost for a DISC engine should not exceed US $1800 to meet the two-year payback requirement, for the relatively stringent criteria assumed.

Based on this study's cost estimate for the additional hardware required and the experience of United Parcel Service with their DISC engine retrofit kits designed for installation at the time of major engine overhauls, it is therefore apparent that the DISC engine concept is economically viable in either original equipment or retrofit form.

TABLE 10 FUEL SAVINGS WITH DISC ENGINE

Typical delivery vehicle with 60% urban and 40% highway mileage

	STD FORD 300	DISC ENGINE	
Fuel	Gasoline	Gasoline	Diesel #2
Annual Mileage, Miles	20,000	20,000	20,000
Avg. Fuel Consumption, USMPG	10.0 x A =	12.5 x B =	14.4
Annual Fuel Consumption, US gal.	2,000	1,600	1,390
Fuel Cost/US gal.	$1.50	$1.50	$1.50
Annual Fuel Bill	$3,000	$2,400	$2,100
Ann. Savings per Vehicle	-	$600	$900

Notes:
1. Data shown for year 1982 in $ US.
2. A = factor of 1.25 developed from Texaco test cycle using van and EPA test cycle using Gremlin car
3. B = factor of 1.15 reflects S.G. difference between gasoline and Diesel #2
4. Fuels savings derived from operation on alternative fuels such as broad boiling range fuel and methanol are not shown since market prices are not yet established.

7.0 TESTING REQUIREMENTS

7.1 Single Cylinder Testing

Texaco's previous TCCS experience and data base may require supplementary testing using either a conventional single cylinder research engine or a custom built test engine based on a single cylinder of a stock Ford 300 engine block. The test engine would be used to evaluate the following parameters prior to the design of a multi-cylinder prototype engine:

- piston design
- injector design
- air swirl pattern
- fuel pump requirements
- spark plug configuration
- ignition system characteristics
- clearance problems
- temperature profiles
- emissions
- fuel consumption
- power output
- operation on a variety of fuels

7.2 Prototype and Production Engine Testing

Multicylinder engines, both prototype and production, would require dynamometer and individual component testing to establish an acceptable level of performance and durability, with the ultimate goal of producing a marketable product.

Complete engine testing would be conducted on a dynamometer featuring automated controls, to permit accurate duplication of test cycles and therefore production of truly comparative data. The use of automatic controls would also minimize costly dynamometer time during the durability testing phase, for example, when thermal shock testing is performed.

During dynamometer testing the following parameters would be evaluated on both prototype and production engines:

- Initial mechanical durability and wear
- Cold and hot starting and restarting
- Idling characteristics
- Power
- Torque
- Smoke
- Emissions
- Vibration
- Operating temperature and warm-up cycle
- Vacuum build-up (brake booster)
- Fuel consumption
- Above tests on variety of fuels
- Above tests on standard Ford 300 engine

Component testing would be carried out prior to or concurrent with engine dynamometer testing to give an early indication of such potential engine problems as wear, fatigue failure, cold temperature seizing, porosity, etc. The knowledge thus gained in a safe and efficient manner on test rigs, which simulate actual or extreme operating conditions, could then be applied to rectify design faults or manufacturing weaknesses.

7.3 Engine Testing in Fleet Service

Prototype and production versions of the DISC engine would be installed in a limited number of Purolator fleet Econoline vans in accordance with vehicle availability and Purolator's commercial commitments at the time of testing. Following initial vehicle performance tests the test engines would be placed in regular service and their performance logged over a one-year period. Records would also be kept of standard Ford 300 vehicles' performance during this period, operating on the same route structure, resulting in a "control vehicle" test concept.

Initially upon being installed in the vehicle, and at regular intervals during the one-year test, the following parameters would be evaluated during DISC engine testing, both on a test circuit and a chassis dynamometer:

Maintenance intervals

Component life

Cold and hot starting and restarting

Acceleration

Driveability —|

Response |----"OPERATOR ACCEPTANCE"

Noise level |

Vibration —|

Retardation (overrun)

Heater operation

Fuel consumption - steady speeds, various

- simulated delivery cycle

Above tests on a variety of fuels

Above tests on standard Ford 300 engine

8.0 PHASE 2 PLAN

8.1 General

The findings of this study have confirmed the suitability of the Ford 300 engine for conversion to the DISC principle and appropriate preliminary engine designs have been proposed in Section 5.0 of this report. User potential, fuel savings and engine conversion cost have also been estimated as part of the Phase 1 work, with the favorable economic analysis results indicating that prototype DISC engines should be designed, built and tested during the next phase of the program.

This Phase 2 work would also include a preliminary market study, further economic analysis, and identification of potential contractors and licencees other than Ford Motor Company for engine manufacture, assembly and distribution. Ford's manufacturing involvement cannot be anticipated until further development work is done.

The relationship of the principal Phase 2 activities within the context of the overall program is shown graphically in Fig. 16, with the details of a plan for implementation of Phase 2 elaborated in the following sections.

8.2 Technical Plan

The technical plan for implementation of Phase 2 was developed jointly by SNC and ORF, drawing heavily upon the experience and advice of Texaco and Ricardo Consulting Engineers Ltd. who acted as engine design and development contractors for the United Parcel Service project.

The approach to be followed for the Phase 2 prototype engine program is outlined in Table 11, consisting of three main sub-programs of engine and component design and development, to be carried out in an overlapping sequence. This approach would afford improved program control, resulting in the achievement of the following program objectives:

1. Product having solid technical basis.
2. Product and components largely manufactured in Canada.
3. Transfer of technology to Canadian agencies.
4. Development of technological depth allowing future alternate designs to be produced in Canada.

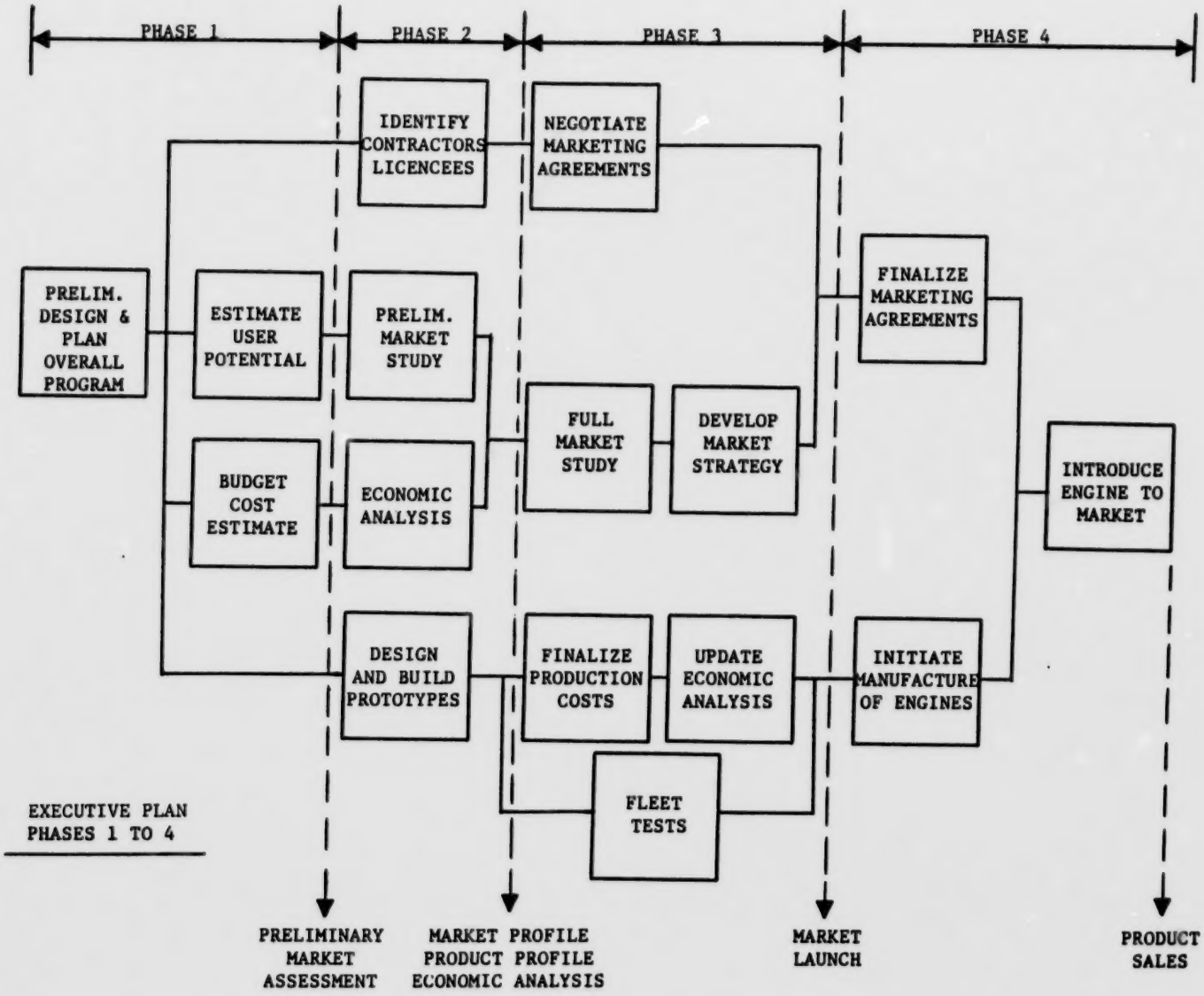


Fig. 16 EXECUTIVE PLAN PHASES 1 TO 4

TABLE 11

APPROACH TO ENGINE DEVELOPMENT PROGRAM

DESCRIPTION OF SUB-PROGRAM	PRINCIPAL OBJECTIVE	ACTION PLAN
1. Thorough program of engineering and development of production engines.	Sound technical basis for product plus volume manufacturing capabilities in Canada	SNC and ORF to design and develop Canadian production engine based on Ricardo-designed prototype engine featuring new crankshaft.
2. Basic research program focusing on DISC concept involving alternate engine internal geometries in important areas.	Sound basis for the technology permitting more freedom in developing new designs, including future retrofits on engines having difficult geometries.	ORF to evolve design and develop advanced DISC engine based on stock Ford crankshaft concurrent with Ricardo program.
3. Development of advanced fuel injection and ignition systems.	Improved marketability and reduced dependence on foreign technology.	Development work to be done by Canadian R & D agencies.

Specific product outputs of the prototype program would consist of the following items of engine hardware:

1. A basic engine and spare parts designed around the concept of a new crankshaft.

2. A Canadian produced engine developed from the design of the basic engine.

3. Advanced technology engines developed in Canada, incorporating advanced designs of fuel injection and ignition systems, and an advanced version of the basic engine featuring the stock Ford 300 crankshaft, offering the potential for reduced DISC conversion cost.

Technical strategy to be followed is presented in Fig. 17, illustrating the roles of SNC, ORF and the engine design consultant, the modes of technology transfer, and the principal steps and sequence of development of the various items of engine hardware.

The bulk of the program work would be performed in Canada. Following basic engine rollover and performance testing, the prototype engines built by the engine design consultant would be sent to Canada for full development testing. All other design and development operations would be Canadian.

SNC

8.3 Organization Plan

The Phase 2 project team would include SNC and ORF staff members, with specialized services provided by Purolator Courier Ltd., Texaco Inc. and an engine design consultant (probably Ricardo).

In general terms, SNC would provide program management skills and would have overall design responsibility to ensure continuity of the program.

SNC would also have equipment procurement responsibility and would perform preliminary market studies and an economic analysis in addition to other detailed project support functions. These activities are estimated to require 1500 man-days of effort.

ORF, possessing engine research facilities and personnel experienced in engine testing, would perform all engine dynamometer test and development duties, including performance, emissions, durability and thermal shock testing.

Component testing and development would also be assigned to ORF, including a program to test and develop fuel injection ignition systems for alternate fuels use.

The design and development of pistons and connecting rods for the advanced version of a DISC engine based on the stock Ford 300 crankshaft would be another of ORF's activities, carried out concurrently with their other tasks for a total of 4000 man-days of work.

Prototype engines, following their development testing on the dynamometer, would be retrofitted to Purolator test vehicles either at ORF's vehicle garage or at Purolator's service facility. The engine retrofit operation would be a simple substitution without the requirement for major vehicle modifications. Following installation, Purolator would assist in establishing vehicle performance requirements and test cycles, and would supply vehicles for testing and fleet performance data.

Texaco and the engine design consultant (Ricardo) would draw from their previous stratified charge engine project experience, providing research data and program assistance as required.

Ricardo would perform single cylinder testing if found necessary, followed by complete prototype engine design, local component procurement, assembly and rollover (preliminary) dynamometer testing.

The participants' activities and work schedule are shown in detail in the attached schedule of activities Fig. 18 presented in bar chart form, with Critical Path Milestones indicating the key project dates for which activity completions are required to avoid slippage in the overall schedule.

A preliminary plan for Phase 2 is shown graphically in SPEC Network form on drawing 6427-0000-45DD-0002, also attached.

8.4 Product Plan

Fig. 19 outlines the proposed approach to product planning and establishing a product marketing strategy, starting with the setting of market goals, and including various stages of market analysis, strategy revision and implementation. Situation feedback, based on historical, actual and forecast information would, following appropriate interpretation, provide the basis for initial product planning and eventual revision of the product and marketing strategy. The resulting interaction between marketing strategy and product planning will lead to market penetration followed by sales growth.

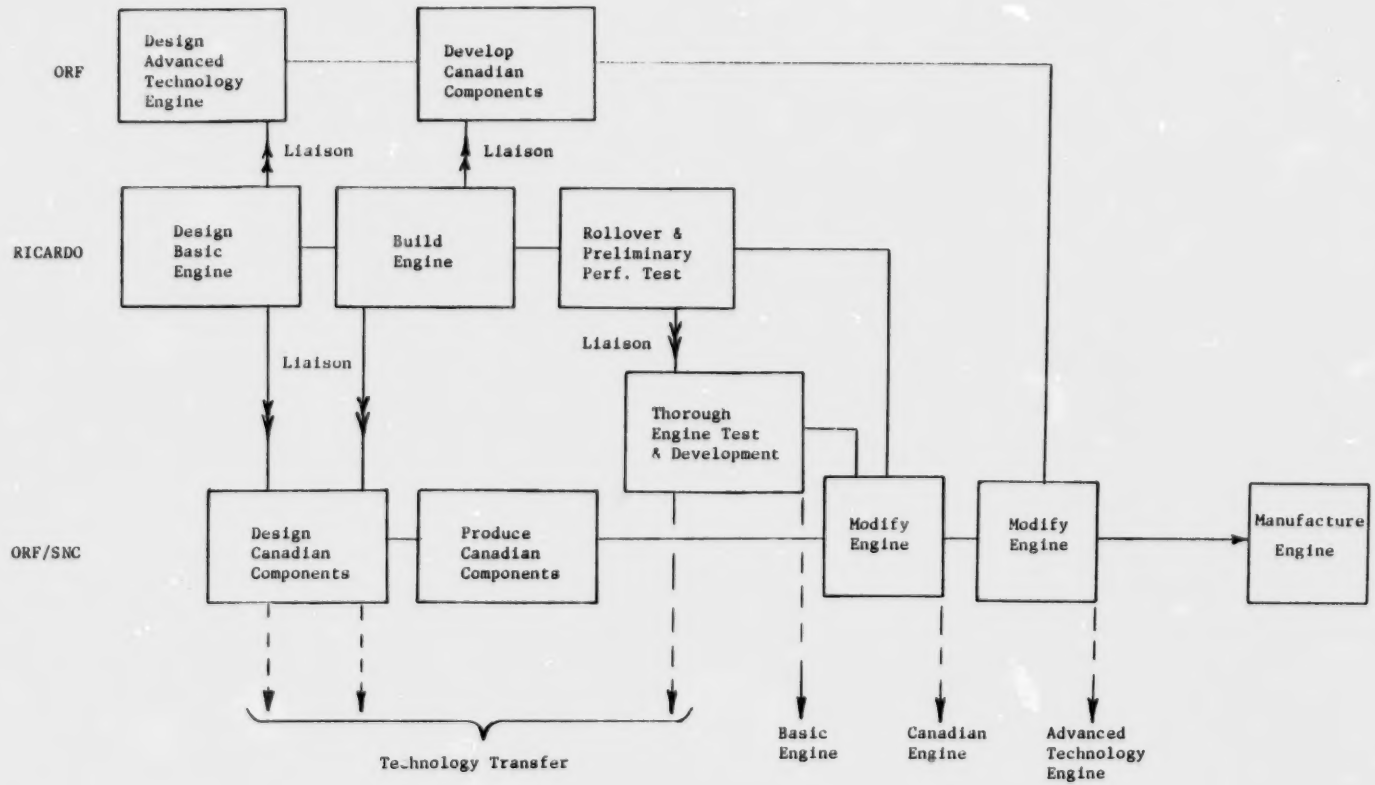
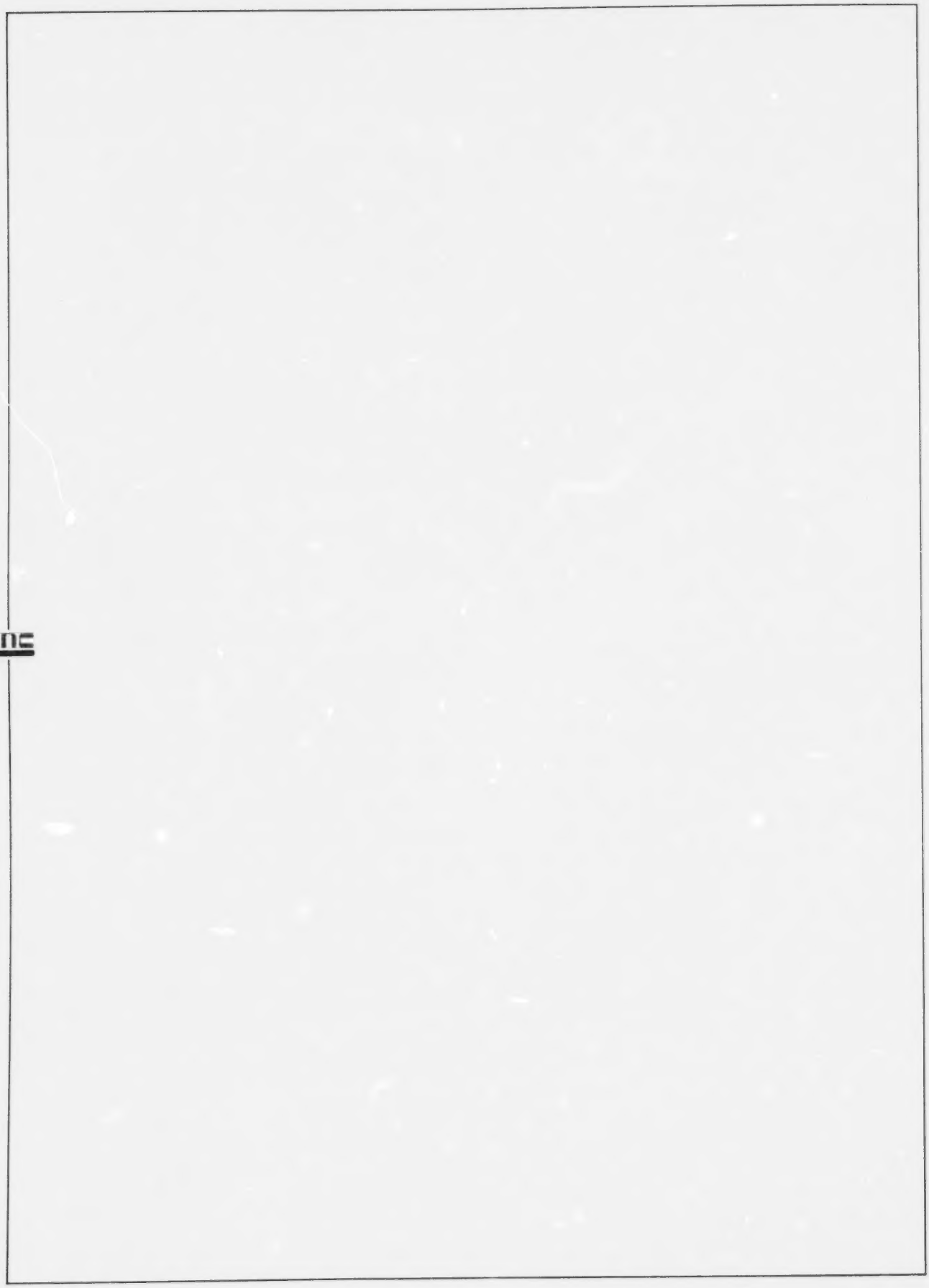


Fig. 17 TECHNICAL STRATEGY



SNC PROJECT CONTROL

CLIENT TDC
PROJECT DISC - PHASE 2

Fig. 18 SCHEDULE OF ACTIVITIES

CONTRACT 6427

SUBDIVISION | ELEMENT: SUBJECT / MINOR | IN CHARGE | SHEET | UPDATED

LEGEND: Critical Path Milestones

PROGRESS %

MONTHS FROM PROJECT START

NO.	ACTIVITY NAME / DESCRIPTION
1.0	SNC
1.1	Meet with Ford re: detail dwgs & components supply
1.2	Negotiate contractual agreements with participants
1.3	Establish engine & vehicle performance requirements
1.4	Select prototype component suppliers and place orders
1.5	Identify production parts suppliers
1.6	Identify assembly and test facilities
1.7	Identify retrofit and servicing constraints
1.8	Develop fleet test program
1.9	Prelim. market study
1.10	Identify potential marketing contractors, licencees, etc.
1.11	Prelim. economic analysis.
2.0	ORF
2.1	Investigate alternate component sources, stock dimensions
2.2	Establish vehicle duty cycle
2.3	Test engine components on test rigs and evaluate
2.4	Develop prelim. operating and instruction manuals
2.5	Install prototype Ricardo engines in vehicles
2.6	Conduct initial vehicle testing on prototype Ricardo engines
2.7	Evaluate vehicle test results and recommend modifications
2.8	Develop test program for alternate fuels
2.9	Develop fuel injection system for alternate fuels and test on rig
2.10	Test and evaluate alternate fuel system on DISC engine
2.11	Test stock Ford 300 for durability with high compression ratio, etc.
	Develop DISC engine based on stock crankshaft & prototype heads incl:
2.12	Establish piston temp. profile
2.13	Stress analysis piston & con. rod
2.14	Layout & design details piston & con rod
2.15	Procure prototype piston & con rod
2.16	Test engines on dyno
2.17	Evaluate test results & modify engine

Agreements Complete

Cyl. Head Quote Order

Confirm engine test facilities available

Receive Engine No. 1

Prototype engine developed

SNC PROJECT CONTROL

CLIENT TDC
PROJECT DISC - PHASE 2

Fig. 18 SCHEDULE OF ACTIVITIES

CONTRACT 6427

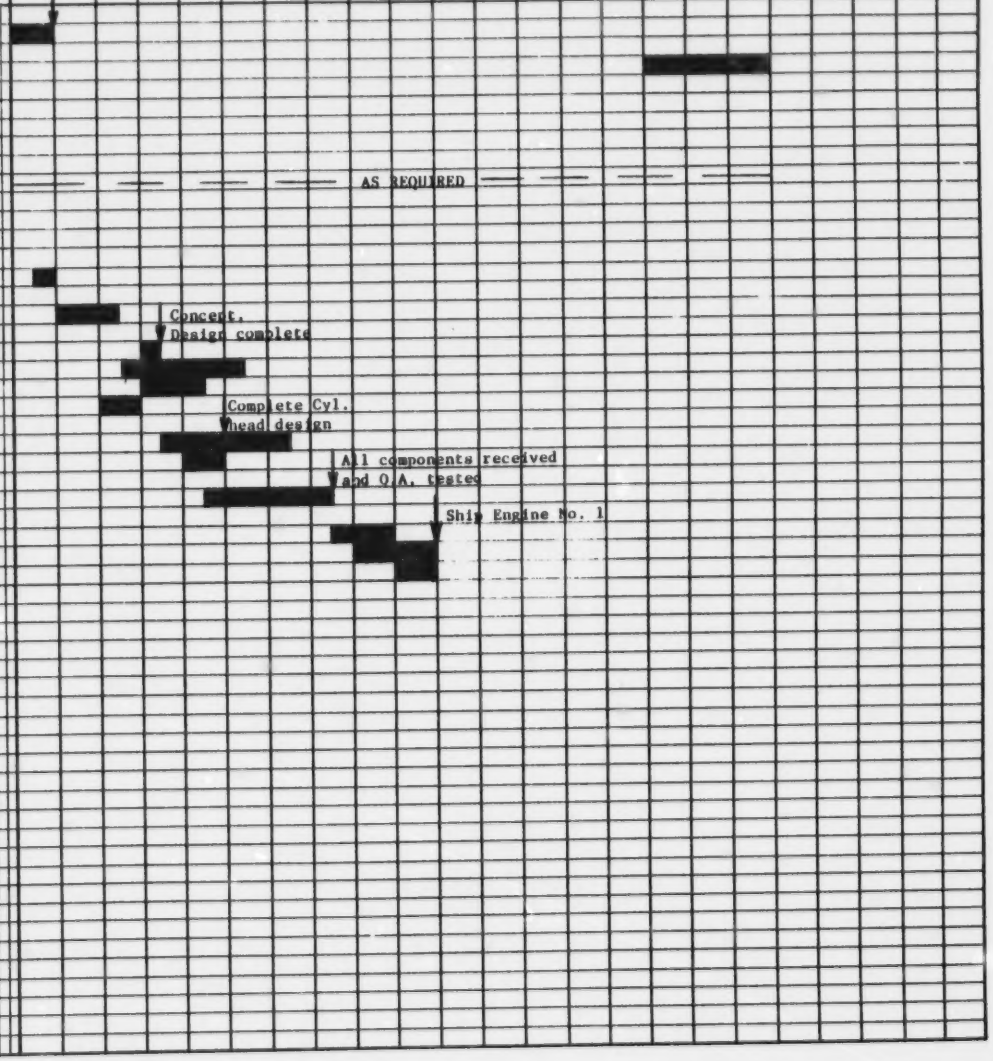
SUBDIVISION | ELEMENT (SUBJECT / MINOR) | IN CHARGE | SHEET | UPDATED

LEGEND: Critical Path Milestones

PROGRESS %

MONTHS FROM PROJECT START

NO.	ACTIVITY NAME / DESCRIPTION
3.0	PUROLATOR
3.1	Establish performance requirements and vehicle duty cycle
3.2	Supply test vehicles and fleet performance data
4.0	TEXACO
4.1	Design assistance and program assistance
5.0	RICARDO
5.1	Review existing Texaco and Ricardo research data
5.2	Study alternative designs and requirement for single cylinder testing
5.3	Single cyl. testing. (If req'd)
5.4	Definitive design
5.5	Port mfr & swirl tests
5.6	Prepare criteria for component performance and durability tests
5.7	Prepare mfg. dwgs. & specs.
5.8	Prepare procurement stds. incl. Q.A. stds & tests.
5.9	Procure prototype parts & mfr. misc. components as req'd
5.10	Assemble engines
5.11	Test engines on dyno
5.12	Evaluate test results & modify engine



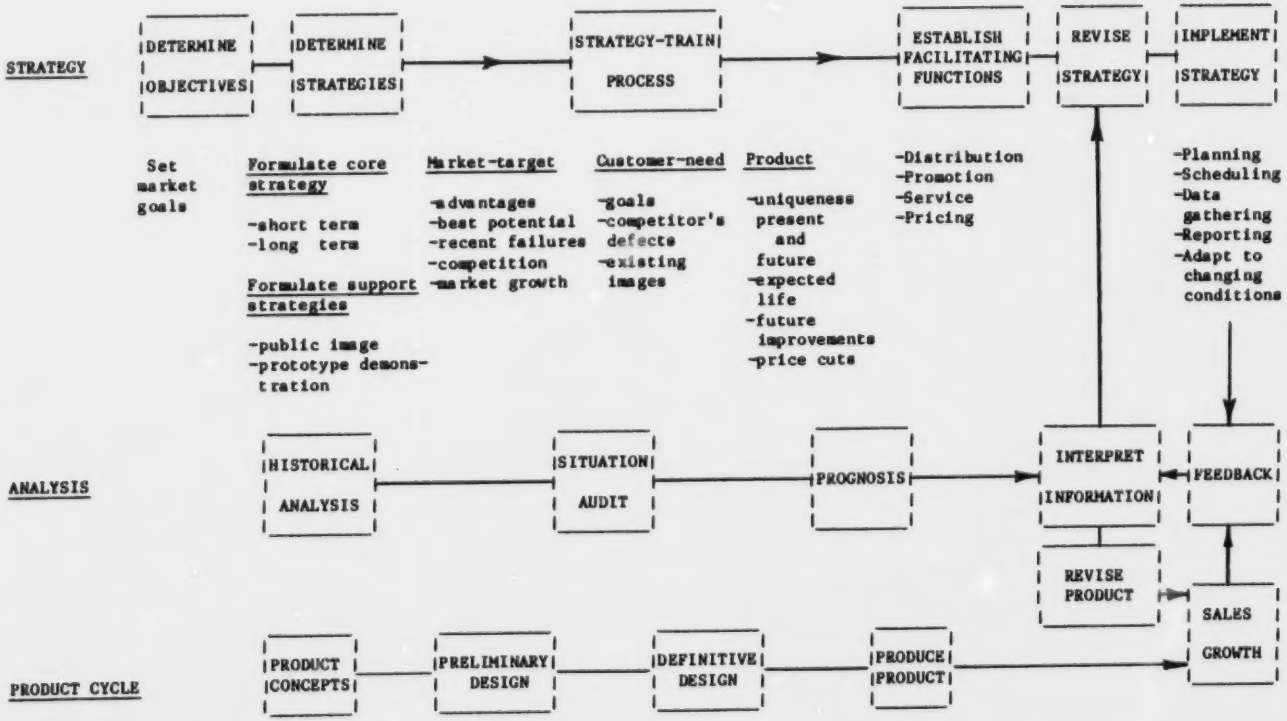


Fig. 19 MARKETING STRATEGY AND PRODUCT PLANNING

8.5 Procurement Plan

8.5.1 Responsibilities

Procurement requirements for the construction and testing of prototype engines will be the responsibility of SNC Inc., who with the participation of ORF and the engine design consultant will identify and select qualified bidders for the supply of equipment and services as required by the program. SNC will prepare documentation and perform all necessary steps to request and analyse quotations (with ORF's participation), negotiate and issue purchase change orders, monitor costs and ensure that procurement documentation is complete and correct. ORF and the engine design consultant will be responsible for preparation of specifications for quotation, technical bid evaluation, expediting of deliveries and technical acceptance of equipment purchased.

At all times DSS and the Steering Commitee will be kept fully informed of procurement status and impending major purchase orders.

8.5.2 Documentation

Procurement documentation will include standardized forms for bid invitation, bid technical evaluation, price breakdown and comparison, procurement timetable and cost reporting.

8.5.3 Program Procurement Requirements

As the prototype engine program develops following the completion of Phase 1, services contracts would be awarded at an early stage to ORF, Texaco and an engine design consultant for the development of prototype engines. Purchases of test equipment, testing supplies, and prototype and stock engine components, with contracts for speciality services and equipment rentals would follow later as the program proceeded and as found necessary by the project management team.

A comprehensive engine component test and development program would be required to upgrade the quality of components manufactured at the start of the production stage. This would involve an intensive procurement effort, since cost and quality problems could necessitate numerous supply contract revisions and changes of supply sources.

TABLE 12 SELECTED SUPPLIERS

Engine Item	Supplier	Location
Cylinder head castings	Holmes Foundry	Canada
	General Motors	Canada
Valve train	Thompson/TRW	Canada
Camshaft castings	CWC Mfg.	USA
Pistons, cast aluminum	Zollner	Canada
	Mahle	Germany
Pistons, forged aluminum	TRW	USA
	Mahle	Germany
Piston rings	Hastings	Canada
Connecting rods, forged	Great Lakes Forgings	Canada
	PC Drop Forgings	Canada
	Dominion Forge	Canada
Crankshaft, forged	Dominion Forge	Canada
	Wyman - Gordon	USA
	SIFCO	USA
Gaskets	Fel-Pro	USA/Canada
Fuel Injection system	Stanadyne	USA
	Robert Bosch	USA
	American Bosch	USA
	CAV	USA
Ignition system	Echlin	USA
Prototype castings	A.G. Anderson	Canada
Gray iron castings	Crowe Foundry	Canada
	Kelsey-Hayes	Canada
	General Motors	Canada
	Benn Iron	Canada

TABLE 12 SELECTED SUPPLIERS (Cont'd)

Engine Item	Supplier	Location
Nodular iron castings	International Malleable	Canada
	Galtaco	Canada
Machining, high volume	Kendon Mfg.	Canada
	Ingersol Machine	Canada
	Linamar Co.	Canada
	Atlas Crankshaft	Canada
	Accurate Crankshaft	Canada
Engine assembly, prototype and low volume	Eastern Rebuilders	Canada
	Central Precision	Canada

8.5.4 Canadian Supplier Network

The majority of the engine components and manufacturing skills required for conversion of the Ford 300 engine to DISC operation are available in Canada from firms presently supplying tooling, parts and services to the automobile industry. A list of selected suppliers, all of whom were contacted to review their qualifications and willingness to participate in a DISC program, is shown in Table 12. Most of the suppliers listed are located in the southern Ontario area due to the concentration of automobile production there, but with further investigation qualified suppliers can no doubt be identified in other regions of Canada. Certainly, the engine assembly operation can be done on a regional basis using authorized Ford engine rebuilders' facilities, two of which are listed in Table 12. Each of these firms is capable of rebuilding and testing approximately 4,000 engines per year.

Apart from the improved distribution of jobs created by regional engine assembly, such an approach would facilitate adaptation and optimization of DISC engines to local operating conditions and fuels.

Engine rebuilders are a logical choice for contract assembly work of this nature, as they routinely are exposed to the problems of short production runs of varying volume expected in the DISC program. Importation of specific hardware, component search and substitution, quality control problems and claims, customer warranties and post-sale service are familiar activities to the engine rebuilder that will also have to be provided for in a DISC engine conversion program.

8.6 Financial Plan

The cost of the Phase 2 prototype engine program, as described earlier in this report, has been estimated in 1982 Canadian dollars, with a summary of the results shown in Table 13. The estimate has been prepared using the following information sources:

- Texaco, who provided overall program scope guidelines based on their previous experience in converting several engines to the DISC principle.

- Ricardo, who prepared a budget quotation for a defined scope of work based on their previous contract work to convert a Chevrolet 292 engine for the UPS project.

- SNC in-house estimating data for similar projects and records of engineering costs and expenses incurred during the performance of this Phase 1 study.

The pattern of cash flow or disbursements to finance the three-year Phase 2 program is expected to be reasonbly uniform at approximately $700,000 per year, reflecting the fact that the program will be executed by a small team with a minimum of overlap between activities.

The costs for tooling applicable to the prototype engine program are included in the Phase 2 estimated total shown in Table 13.

The additional costs for engine tooling suitable for the volume manufacturing phases subsequent to Phase 2 have been estimated from budget quotations solicited from qualified Canadian suppliers, totalling approximately $500,000 expressed in 1982 funds.

TABLE 13 PHASE 2 COST ESTIMATE SUMMARY

Item	$ Cdn 1982 (000)
SNC services	500
ORF services	1,200
Purolator services	15
Texaco services	75
Engine design consultant services	550
SUB-TOTAL, services	2,340
Materials	150
Expenses	
- travel and subsistance	100
- reproduction	5
- communication	15
- shipping	20
- computer	20
SUB-TOTAL, materials and expenses	310
GRAND-TOTAL, Phase 2	2,650

9.0 DISCUSSION

The National Energy Program seeks to eliminate oil imports by 1990. DISC technology, taken to the extreme case of application to all Canadian vehicles, would potentially accomplish this objective. On its own merits the DISC engine is significantly more efficient than the gasoline engine. It has the added advantage that it can operate on a wide range of fuels, which would permit introduction of alternative fuels on a regional basis and would also permit more efficient operation of refineries on the basis of quantity of vehicle fuel recovered per barrel of crude, since fuel specification requirements could be relaxed without penalty. This extreme scenario is, of course, unrealistic, but serves to illustrate the significance of the technology. The concept of widespread application of a new technology also focuses attention on a range of related questions: How will the theoretical design be converted to hardware? How will the technology transfer be effected, and who will be the recipient of the technology? Who will undertake production? What are the pertinent market mechanisms? And are there outstanding problems which should be resolved?

These questions have in large measure been addressed in the body of this report, but require further comment.

The design applications study has probed the mechanical equipment aspect to ensure that design functional constraints can be accommodated. However, an examination of emission performance has not been made to the same depth. This is known to be a potential problem area, especially for hydrocarbon emissions at low power outputs.

The DISC engine's potential to operate on methanol fuel should also be examined. Performance, emissions, engine durability and components compatibility are factors which, to date, have not been thoroughly evaluated for conditions of sustained methanol operation.

Existing DISC engine designs have employed a conventional mechanical governor for the fuel injection system and an electronic ignition system triggered by the fuel injector. In a more advanced engine, as is here anticipated, an electronic fuel injection system is envisaged with sensors and feedback loop controls, and a more advanced electronic ignition system. While such systems involve more development work, the end result would be an engine with improved performance.

The question of the cup-in-piston form has also been addressed in the study. Although it has been ascertained that a suitable cup can be defined, the "best" design has by no means been identified. Further development/testing will be required which will potentially lead to an advancement in state-of-the-art knowledge.

The issue of identification of an organization to undertake production is probably the most crucial to overall program success. All of the components can be made in Canada, and the rebuild/retrofit procedure poses no fundamental problems. However, the engine is not manufactured in Canada and the local market alone would not warrant production in Canada. Although at one time the 300 c.i.d. 6 cylinder engine was produced in Windsor, production has now been concentrated in Cleveland, Ohio and a further reorganization of this activity would not be practical. Ford Motor Company, currently pursuing its own alternative fuels engine programs, would prefer that more work be done on DISC development before making a commitment to manufacture.

Thus a licensed manufacturing agency would be required. A number of interested companies were contacted and there is every reason to believe that Canadian production would take place. However, pending demonstration of an operating engine, no firm commitments can currently be made.

The importance of an operating engine that could demonstrate the performance available from DISC technology should not be underestimated. Vehicle testing and demonstration of operation would generate favorable publicity in the manner of most other product introduction programs, sparking consumer requests for OEM installations of DISC engines. More than one major truck engine manufacturer contacted during the study confirmed that user demand, generated by successful trial installations or other previous experience, is the key ingredient in becoming an original equipment engine option.

Other technologies offering improved fuel efficiency currently compete with DISC for manufacturing status, including propane conversions, turbocharged diesel engines, and advanced conventional gasoline engines featuring precise fuel and ignition system controls. Each of these technologies possesses particular advantages, and captures its market share accordingly. Similarly, changing market, fuel and regulatory conditions will distort these marketplace advantages (rapidly in some cases), creating new demands for innovative technologies.

In such a context, the development of the DISC engine must be treated as a risk venture. In this regard, the study has addressed the technology application, economics, market and needs of the development phase so as to ensure a successful program.

10.0 CONCLUSIONS AND RECOMMENDATIONS

10.1

The Direct Injection Stratified Charge engine technology developed by Texaco Ltd. has been examined and its application to the Ford 300 c.i.d. 6 cylinder engine was found to be technically feasible.

10.2

The economics and market aspects of an appropriate engine commercialisation program have been evaluated and were found to be viable. A Canadian Original Equipment Manufacturer will have to be identified prior to implementation of such a program.

10.3

A development program using Canadian resources has been identified to achieve an advanced engine design with minimum risk. This development program should be pursued to the prototype engine stage to ensure a DISC engine development capability in the context of a "contingency technology" available to Canadians.

11.0 APPENDICES

APPENDIX A - REFERENCE LITERATURE

REFERENCE LITERATURE

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6. UPS Stratified Charge Engine Adopts Texaco Technology to Power Package Delivery Vans, June 1980, J.M. Lewis and W.T. Tierney.

7. United Parcel Service Applies Texaco Stratified Charge Engine Technology to Power Parcel Delivery Vans, Nov. 1980, SAE 801429, Lewis and Tierney.

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10. Development of Alternative Engines and their Fuel Requirements, Sept. 1975, Downs and French.

11. Chemical Engineers' Handbook, 1973 edition, Perry and Chilton.

12. Standard Handbook for Mechanical Engineers, 1967 edition, Baumeister and Marks.

13. Petroleum Products Handbook, 1960 edition, V.B. Guthrie.

APPENDIX B - DRAWINGS

SIC

PROJECT MANAGEMENT

1400

SIC

PRELIM MARKET STUDY

400

SIC

IDENTIFY PRODUCTION PARTS SUPPLIERS INCL CDN SOURCES

180

SIC OR PUBLICATION ITC

INTERNAL REVIEW MEETING

SIC

IDENTIFY, RETRIEVE & TRACKING CONSTRAINTS

60

SIC

PRELIMINARY ECONOMIC ANALYSIS

180

STEERING COMMITTEE MEETING

SIC / TDC / DSS

STAFF MAJOR EXPENDITURE COMMITMENTS

SIC

IDENTIFY POTENTIAL MARKETING/PRODUCTION CONTRACTORS/LICENCEES ETC.

240

SIC

IDENTIFY ASSEMBLY & TEST FACILITIES

120

SIC/PUBLICATION

DEVELOP PILOT TEST PROGRAM

90

SIC

DEVELOP PRELIMINARY MARKETING STRATEGY

240

SIC

SELECT PROTOTYPE COMPONENT SUPPLIERS

90

R CARD

DEFINITIVE DESIGN

200

R CARD

PROTOTYPE ENGINE & VEHICLE TESTS

R CARD

ASSEMBLE PROTOTYPE ENGINE & PRELIMINARY PERFORMANCE TESTS

35

DR

TEST ENGINE FOR PERFORMANCE & DURABILITY

140

PUBLICATION

APPLY TEST VEHICLES

DR

INSTALL PROTOTYPE ENGINE IN VEHICLES

60

PUBLICATION/DR

INITIAL VEHICLE TESTS/EVALUATION AND RECOMMENDATIONS FOR MODIFICATIONS

200

ALL PARTICIPANTS

INTERNAL REVIEW MEETING

STEERING COMMITTEE MEETING

DR

DEVELOP PRELIMINARY OPERATING & MAINTENANCE MANUAL

120

DR

INVESTIGATE ALTERNATE COMPONENT SUPPLIERS & STOCK DEVELOPMENT

80

DR

SELECT & DEVELOP FOR ALIGNMENT

DR / SIC

DEVELOP PROGRAM FOR ALTERNATE FUELS

200

DR

DESIGN & DEVELOP FOR ENGINE

DR

TEST & EVALUATE ENGINE

ONTARIO RESEARCH

Sulzer Jennings & Chenevert Inc.

CLIENT: TDC

PROJECT: DSS ENGINE PROJECT 6427

TITLE: PRELIMINARY SPEC NETWORK PHASE 2

DESIGNED: PAR/LAC/DR

APPROVED

DRAWN: MCH/ML ATTN/LAC

CHECKED:

SCALE:

DATE: 28/07/82

Project Engineer

Project Engineering Manager

Client

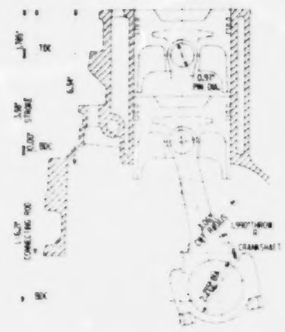
CONT. No. 6427 | DRAWING CODE 000045DD | SERIAL No. / REV. 0002

REFERENCE DRAWINGS

No. | REFERENCE DRAWINGS

No. | DATE | REVISIONS | BY | CHK | APP

No. | DATE | REVISIONS | BY | CHK | APP



REFERENCE ARRANGEMENT

STD. ENGINE
300 IN³ DISPLACEMENT
3.0 L/R

ARRGT. NO.1
STD. BORE AND CRANKSHAFT
FLAT PISTON CUP
300 IN³ DISPLACEMENT
3.0 L/R

ARRGT. No.2
STD. BORE AND CRANKSHAFT
FLAT PISTON CUP
300 IN³ DISPLACEMENT
3.0 L/R

ARRGT. No.3
STD. BORE AND CRANKSHAFT
FLAT PISTON CUP
300 IN³ DISPLACEMENT
3.0 L/R

ARRGT. No.4
STD. BORE AND CRANKSHAFT
FLAT PISTON CUP
REDUCED PIN DIAMETER
300 IN³ DISPLACEMENT
3.0 L/R

RECORD OF DRAWING ISSUE	No	REFERENCE DRAWINGS	No	REFERENCE DRAWINGS	No	DATE	REVISIONS	BY	CHK	APP

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PRINT No.

Surveyer, Nenniger & Chenevert Inc.
Consulting Engineers, Montreal, Canada

DESIGNED	P.JARDIN/CAZUR	APPROVED
DRAWN	M.POULIN/CADD	Project Engineer
CHECKED		Project Engineering Manager
SCALE	NTS	Client
DATE	82-10-27	

CLIENT: TDC

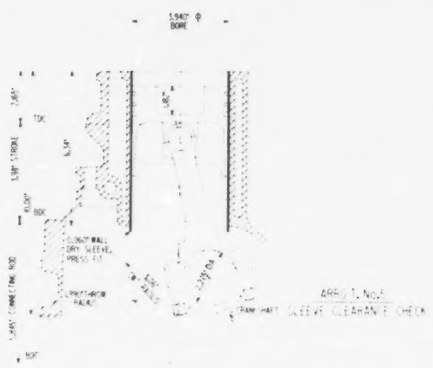
PROJECT: D I S C

TITLE: SNC FORD 300 CID TCCS CONVERSION

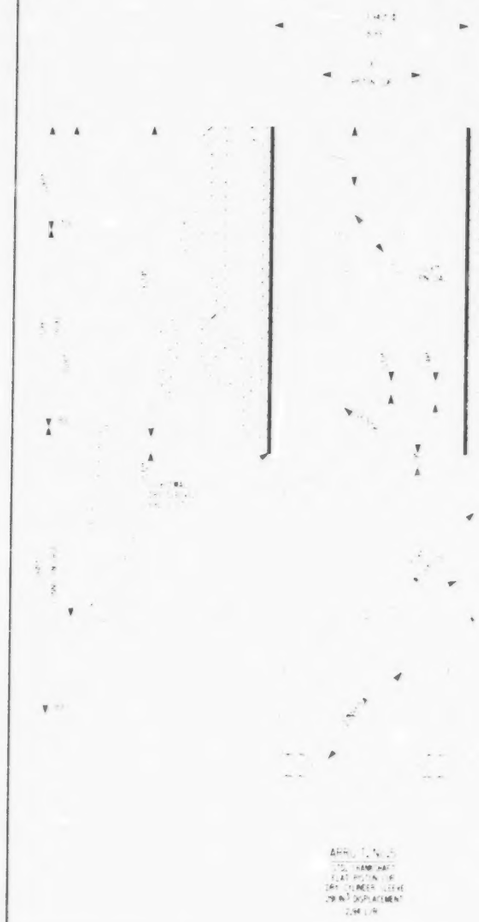
CONTR No.	DRAWING CODE	SERIAL No.	REV.
642700004500		0003	0

CADD: 6427 0002

REFERENCE ARRANGEMENT
STOLENDE
MAIN DISPLACEMENT
GEAR



ARRGT. No.5
FAIRLEAD SLEEVE CLEARANCE CHECK



RECORD OF DRAWING ISSUE		No. REFERENCE DRAWINGS	No. REFERENCE DRAWINGS	No. DATE REVISIONS	BY CHK APP			

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PRINT No.

Sauvageau Hannegan & Charbonneau Inc.

DESIGNED		APPROVED	
DRAWN		PROJECT ENGINEER	
CHECKED		PROJECT ENGINEERING MANAGER	
SCALE	N.T.S.	CLIENT	
DATE			

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TITLE
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TOOLS CONVERSION
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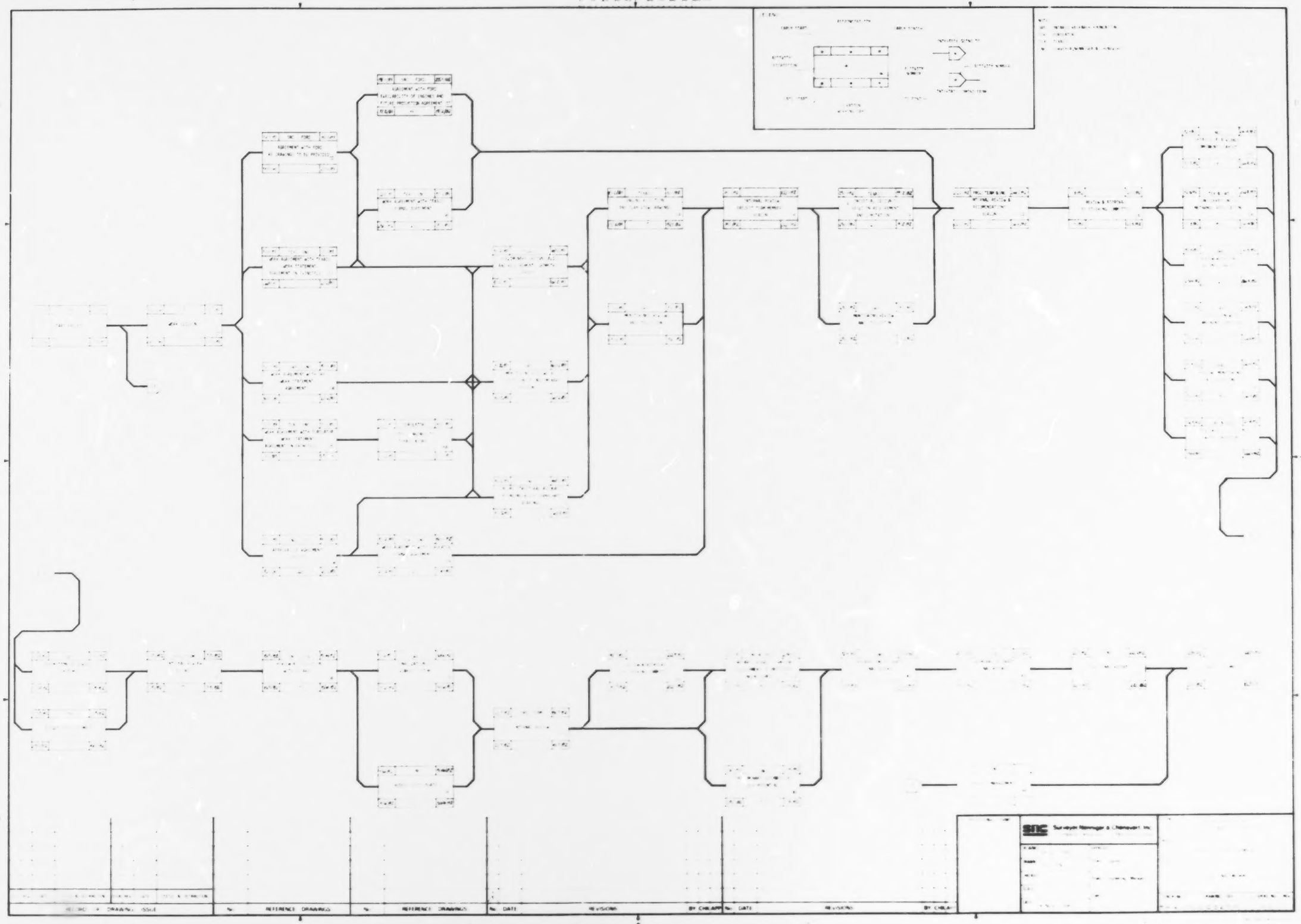

FRONT

INC. CASE AND TYPE NAMEPLT

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REVISIONS			
BY	DATE	DESCRIPTION	SYMBOL

APPROVED	
BY	DATE
JAN 13 1982	

REFERENCE DRAWINGS

TEXACO INC

RESEARCH & TECHNICAL DEPARTMENT

TEXACO RESEARCH CENTER

BEACON, N. Y.

INITIALS	DATE	DEPT. CS	SCALE FULL
DRAWN BY JPMC	1/11/82	ENGR. BY SNC	CS-D-6110
CHK'D BY		D. M.	

2N3 FORD 300 TWC CONVERSION

VALVE GEOMETRY

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REVISIONS			SYMBOL
BY	DATE	DESCRIPTION	

APPROVED	
BY	DATE

REFERENCE DRAWINGS

TEXACO INC.

RESEARCH & TECHNICAL DEPARTMENT

TEXACO RESEARCH CENTER

BEACON, N.Y.

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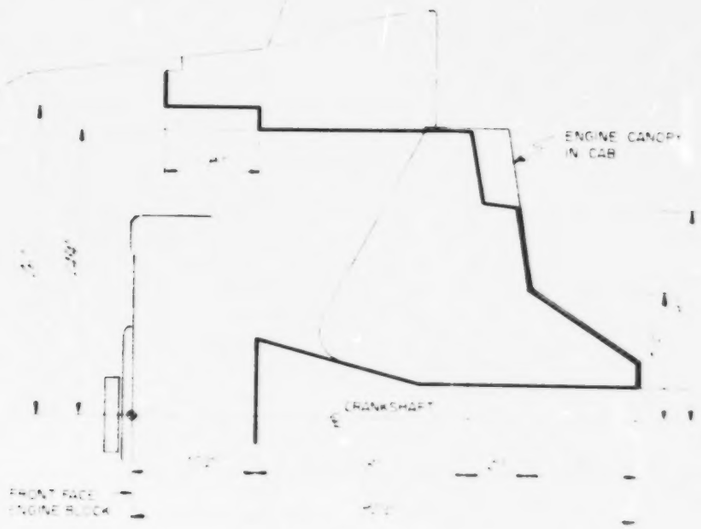

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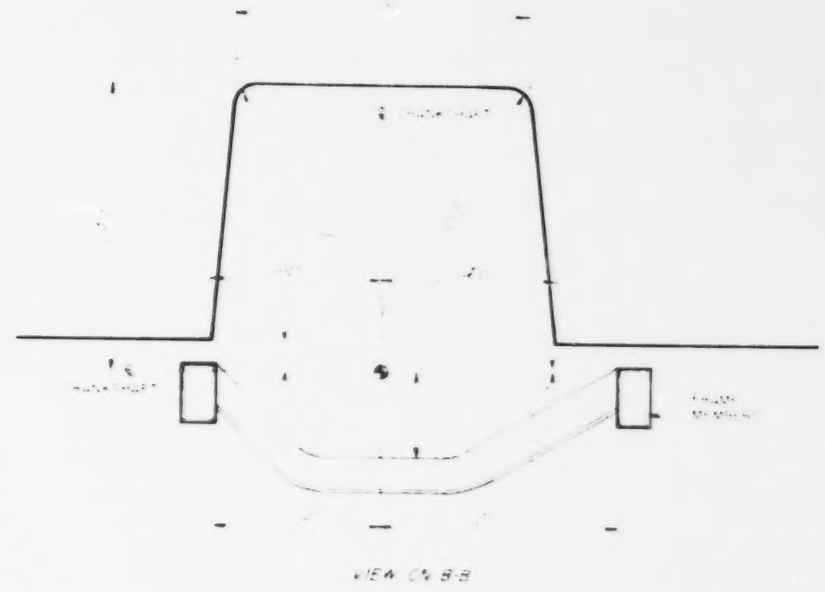
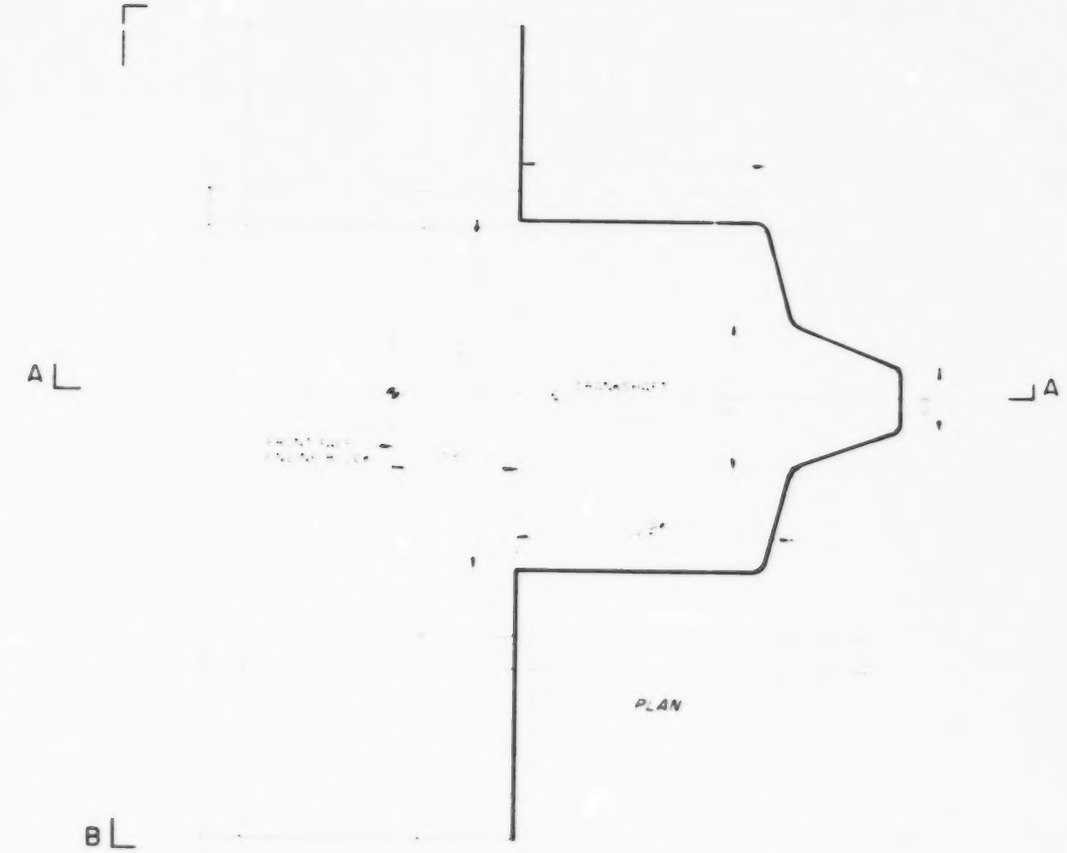


VIEW ON B-B

B



PLAN

ENGINE COMPARTMENT DIMENSIONS FOR
1977 FORD ECONOLINE VAN

ONTARIO RESEARCH FOUNDATION

APPENDIX C - VEHICLE FUEL/REFINERY INTERACTION

APPENDIX C - VEHICLE FUEL/REFINERY INTERACTION

Optimizing the Transportation Fuel Supply *

The potential for engine operation on a more energy-efficient fuel is of importance to the conservation of our energy resources. Motor vehicle fuel economy is certainly a dominant objective of vehicle use and design at the present time. It is equally important to consider, however, the inter-relationship that must exist between the vehicle engine and its fuel specification. In reality, the manufacture of the fuel and the efficiency of the vehicle in which it is used must be considered as a total system. Optimizing the system becomes a matter of obtaining a maximum number of miles of transportation from a barrel of crude while supplying other necessary petroleum products.

Before discussing the impact that a selection of engine type and the fuel can have on the available transportation resources for the future, we believe it would be desirable to touch briefly on some of the background, events, and facts that make this subject of such vital importance.

For many decades now, petroleum resource experts from governments, industry, and academia have been predicting the advent of the situation in which the world now finds itself. That is, the fact that the projected world demand for petroleum will exceed the supply in the near future.

The future objective must be "more miles per barrel of crude oil." This means that we should not take for granted the availability of high octane, high cetane or narrow boiling range fuels, but must look just as hard at the engine system as at its fuel in seeking transportation means for the future.

Before examining a few examples of the extent to which the efficiency of the system comprising a vehicle, its fuel, and the refinery that manufactures the fuel, can be affected by engine and fuel options, it would be worthwhile to look at a few simple aspects of engines and their fuels. Figure 3-1 shows several typical fuels placed in a band of an octane and cetane number relationship. Octane, a requirement for high performance gasoline engines, is a measure of a fuel's resistance to spontaneous ignition or knock and Cetane, desirable for diesel engines, is a measure of a fuel's ease of spontaneous ignition, which is necessary for high speed engines and low noise level, lower compression ratio units. These measures are the opposite extremes of the same combustion characteristic. Good diesel fuels are largely paraffinic, fairly straight-chained hydrocarbon molecules. At the present time there is no large volume petroleum process that is economically viable for altering gasoline-type molecules to make a good diesel fuel.

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* Prepared by Texaco Inc.

In addition to the classic octane and cetane requirements of the gasoline and diesel engine, respectively, other major factors have come into the picture in recent years.

Environmental concerns over the gases of the exhaust of the gasoline engine have resulted in a forced reduction in the use of lead and other compounds as additives to gasoline for octane improvement. In the United States and Japan, the total removal of lead from gasoline has been mandated in order to accommodate the catalytic converter. These actions have resulted in a reduction in the octane number of the available fuels and a commensurate reduction in the compression ratio of the engines in order to avoid severe knock. The effect of these changes on the relative fuel economy of a typical engine is shown in Figure B-2.

Growing concern over the health effects of the particulate emissions of the diesel engine will have an effect on its future design. Until recently, exhaust opacity or smoke number was the criterion for engine performance acceptance. However, more recently investigations have been directed toward particulate weight measurement which poses a more stringent control on the exhaust of a diesel. The popularity of a diesel, of course, resides in its good part-load fuel economy, such that, in variable speed and load service, a diesel engine will provide 25 to 30 percent more miles per gallon of fuel than will a similar gasoline engine under comparable service conditions. For our study we assumed that the light duty vehicle diesel engine would provide a 30% fuel economy improvement over the gasoline engine.

Let us now look at the table on page B-2 which is a summary of a study* that was made to consider different engine and fuel types with the U.S. refinery industry supplying the entire national product slate, using as a base case one where all the fuel is made into leaded gasoline.* For each of the study cases, fuel is supplied to a transportation system operating 4.3×10^9 road miles a day. In addition to this, a fixed quantity of home heating oil, aviation jet fuel, road oils, lubricants, waxes, petro-chemical feedstocks, and other required products is supplied. Four separate cases were studied. The first is the base case in which all gasoline is leaded, 96 Research Octane Number (RON), typical of that which was available prior to 1975. For the second case the assumption was that all gasoline fuelled vehicles were supplied with a 91 RON unleaded gasoline. This reduced the relative fuel economy to 93% (see B-2). In this case the same amount of diesel fuel was used as was the situation in the first case. For the third case, the amount of diesel fuel that could be manufactured was maximized. Note that, in the process, a large volume of gasoline was required to meet the transportation fleet fuel demand because insufficient diesel fuel was available for the fleet mileage requirement. The gasoline was a 91 Research Octane Number unleaded product. The last case looks at a situation where all

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*For this study crude mixture and refinery configuration were fixed, except for the middle distillate hydrotreater used for product sulfur control primarily.

FIGURE B-1

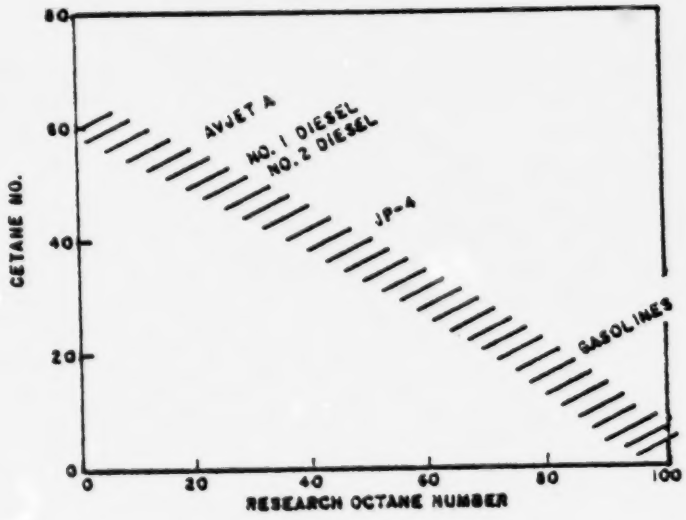
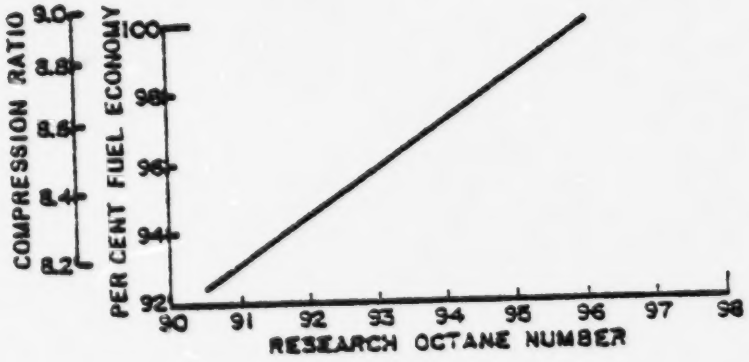


FIGURE B-2

INTERRELATIONSHIP-RESEARCH OCTANE-COMP. RATIO-% FUEL ECONOMY



REFINERY TRANSPORTATION FUEL PRODUCTION

CASE	LEADED GASOLINE	UNLEADED 91 RON (GASO)	MAX DIESEL UNLEADED GASO (91 RON)	BROAD RANGE FUEL (100-650°F)
CHARGE STOCKS BPCD*				
CRUDE	100,000	107,518	98,898	85,095
OTHER STOCKS	7,900	7,900	7,900	7,900
	--	--	--	--
REFINERY REQUIREMENT % CRUDE	8.0	10.7	ENERGY 7.1	5.2
	--	--	--	--
TRANSPORTATION FUEL BPCD				
GASOLINE	54,854	59,893	33,750	
DIESEL	10,131	10,131	27,668	10,131
100-650° FUEL				42,195
	--	--	--	--
PROTECTED PRODUCTS BPCD	34,851	34,851	34,851	34,851

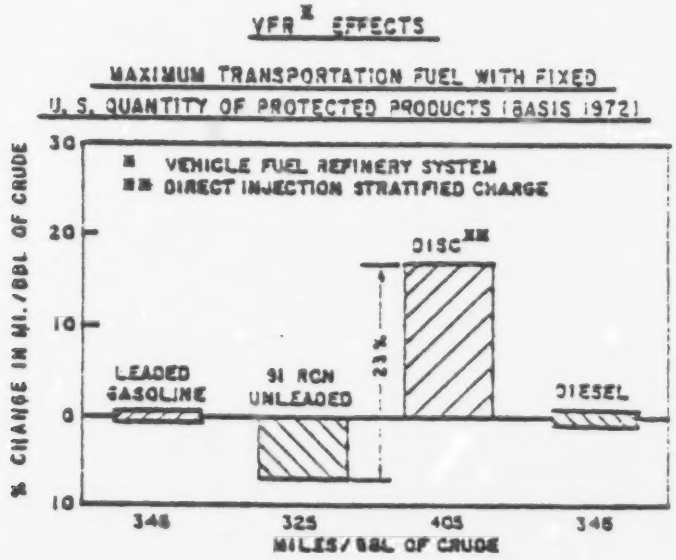
*BARRELS PER CALENDAR DAY

(SEE PAGE 15 FOR CALCULATION METHOD)	MILES PER BARREL OF CRUDE			
MILES PER BBL CRUDE	345	325	345	405

BASIS: 12.07 MPG (U.S. NATIONWIDE FUEL ECONOMY AVERAGE BASIS LEADED GASOLINE - SEE BIBLIOGRAPHY REF. 5)
1.00 RELATIVE FUEL ECONOMY LEADED GASOLINE AVG RON-96
0.93 RELATIVE FUEL ECONOMY UNLEADED GASOLINE RON-91
1.30 RELATIVE FUEL ECONOMY DIESEL AND DIRECT INJECTION STRATIFIED CHARGE ENGINES

but the heaviest diesel trucks in the transportation fleet utilize a direct-injected, stratified-charge (DISC) engine. Here, its fuel, unleaded, is manufactured to supply this vehicle fleet. The engine has been shown to have a fuel economy approximately equivalent to that of a small automotive diesel.

An indication of the efficiency with which the refinery can manufacture the fuels for each study case is reflected in the percent of crude energy charged to the refinery in order to manufacture its required product slate. The process energy required for each case can be seen in the value of the refinery fuel requirement. In bar graph form these several cases are shown below where vehicle and refinery efficiency are combined as miles per barrel of crude.



When one considers that we are moving into an era that, in the next 25 or 30 years, will see the introduction of substitute liquids to replace crude petroleum products it is absolutely necessary that every possible step be taken to select the optimum engine-fuel system in order to insure that the objective of more miles per barrel of crude material can be accomplished.

The passenger car engine on the drawing board today will still be on the road in the year 1995. The new truck engine of today will still be in active service after the year 2000. We cannot afford the luxury of sitting back and waiting until something changes. The engine and vehicle designer, the transportation system specialist, the producers of petroleum and its substitutes and, the refining technologists must work as a team to make the decisions for the transportation systems of the future. It is not enough to be concerned with motor vehicle fuel economy, we must be concerned with transportation system efficiency from the basic natural resource to the vehicle on the road.

APPENDIX D - NOTES ON PRODUCTION LINE LIMITATIONS

APPENDIX D - NOTES ON PRODUCTION LINE LIMITATIONS

1. Engine Plant Production Operations

Initial operations in the mass production of engines take place in the foundry, where parts are cast, forged or stamped followed by such processes as hardening, hardfacing, annealing and tempering.

After these preliminary forming operations are complete, engine parts are finished to the required dimensions using various machining steps, including broaching (cylinder head faces), reaming (valve guides), grinding (crankshaft journals) and honing (cylinder bores).

Parts are then assembled, being usually selected for best fit from graded batches. Experience has shown that lower production costs result from allowing wider manufacturing tolerances, measuring and grading finished sizes, and selecting components for assembly to suit, instead of attempting precision manufacture of all components with no need for matching.

2. Factors Affecting Manufacturing Tolerances

Cost items such as engine blocks, camshafts and manifolds frequently suffer distortion for a number of foundry-related reasons, with the most common cause being core float and shift during the pouring operation.

Forged components gradully assume inaccurate shapes due to wear of the dies after lengthy periods of forging service. Good die design can delay the wearing action from producing reject-quality components, and spot checks will give adequate warning of the requirement for die replacement.

Machine tool wear can account for large variations in production line tolerances, but this source of error can be controlled through the use of automated equipment that compensates for wear by monitoring the finished dimensions of the part produced. Automated equipment is also useful in limiting human operator error.

APPENDIX D - NOTES ON PRODUCTION LINE LIMITATIONS (Cont'd)

2. Factors Affecting Manufacturing Tolerances (cont'd)

Good production design techniques can help control tolerances, thereby both improving product quality and reducing scrap caused by finishing errors. Intelligent selection of the type and sequence of operations, materials and specific machine tools is important. Specification of checking methods, including jig design, that avoids the possibility of accumulation of tolerances will help to achieve the desired accuracy.

3. Factors Affecting the Cost of Production

The following production conditions lead to reduced unit cost:

- multiple machine tool heads that increase tool utility
- employment of multiple, simultaneous operations such as gang boring and honing of engine block cylinders
- use of automatic line transfer equipment to reduce hand operations and waiting time
- use of numerically-controlled machinery where practical
- specification of conventional designs and production processess that reduce the need for new tooling development.

APPENDIX E - ORF FINAL REPORT

D R A F T

DEPARTMENT OF SPECIAL PROGRAMS

Centre for Alternate Fuel Utilization

TCCS - DIRECT INJECTION STRATIFIED CHARGE ENGINE DEVELOPMENT

Final Report No. P-3695/I/1
Phase I

for

SNC Inc.
P.O. Box 10
Desjardins Postal Station
Montreal, Quebec
H5B 1C8

Attention: Mr. F. Eyre

W. Goetz

October 18, 1982

ONTARIO RESEARCH FOUNDATION

SHERIDAN PARK RESEARCH COMMUNITY

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FIGURE 1: Crankshaft with Connecting Rod and Piston of Ford 300 H Engine

FIGURE 2: Close-up of Crankshaft with Connecting Rod and Piston of Ford 300 H Engine

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APPENDIX A : Drawings: - Engine Layout
- Engine Compartment of Ford Econoline Van

APPENDIX B : Potential Suppliers for Parts Manufacture

APPENDIX C : Flow Chart of Proposed Phase II Activities

EXECUTIVE SUMMARY

INTRODUCTION

This report summarizes the activities performed by ORF during Phase I of the project, "TCCS - Direct Injection Stratified Charge Engine". The objective was to determine the feasibility of using the 300 H Ford 6 cylinder in-line spark ignition engine as a base engine to be operated on the Texaco stratified charge principle, and arrive at a preliminary design.

This included:

- evaluation of the engine block, crank geometry and fitting of a cup in the piston;
- layout of a new cylinder head incorporating new valve geometry, new ports (intake swirl port) and an injector and spark plug per cylinder while maintaining compatability with the engine block (bolt pattern, water passages);
- layout drive for injection pump and other accessory drives (e.g. distributor);
- identification of Canadian sources to manufacture and supply components and parts;
- development of a work statement for Phase II, that is, detailed design, manufacture of parts, prototype assembly, prototype development and engine evaluation in a vehicle.

FEASIBILITY

As part of the feasibility study, ORF obtained a scrap engine from Purolator to identify the crank geometry and possibilities for fitting the required cup in the piston. Figures 1 and 2 show the crankshaft - connecting rod - piston assembly. The l/r ratio of the stock engine is already 3.12 which is near the lower limit, commonly accepted in the automotive industry. The photographs confirm the small space left between the weights on the crankshaft and the bottom of the piston. Suggestions were made to overcome this problem, such as machining of crankshaft weights and sleeving of the cylinders to accommodate a shorter connecting rod. Other ideas included a shorter crank radius. Several configurations (four) were developed but no final decision was made at that time.

ENGINE LAYOUT

A rough engine layout was developed based on the Ford block. The layout included positioning of the injection pump, the distributor, water pump, vacuum pump, shapes for intake and exhaust manifold. A figure showing this layout is attached in Appendix A.

In order to identify the space limits of the engine bay, a Ford van was obtained from Purolator since this corporation was identified as a fleet operator for testing the first vehicles. The details of the geometry are layed out in a drawing "Engine Compartment Dimensions for 1977 Ford Econoline Van", which is also attached in Appendix A.

IDENTIFICATION OF CANADIAN SOURCES

In co-operation with SNC a list of potential manufacturers for diversified parts have been contacted in order to identify a contact person, their product line, their capability of prototype manufacture and to obtain rough

estimates about costs for manufacture of prototype parts. Potential suppliers were located by checking the Thomas Register and contacting APMA (Automotive Parts Manufacturing Association). A sheet was prepared and specific answers were solicited which would qualify that organization as a potential supplier. The suppliers contacted and their answers are listed in Appendix B.

PREPARATION OF WORK STATEMENT - PHASE II

During the discussions of Phase I, Ricardo was identified as a subcontractor which would perform the basic design and prototype manufacture. ORF would be involved on a large scale in prototype assembly and testing based on Canadian Manufactured parts. In addition, an advanced concept may be developed incorporating a Canadian developed and manufactured ignition system and specifically developed (by U.S. or European sources) injection equipment.

A more detailed layout is provided in the following section while Appendix C contains a flow chart identifying the inter-relationship between activities.

1. Contract Establishment
   - Series of meetings aimed towards project planning and procedures.

2. Performance Specifications
   - Baseline engine specifications are established.
   - Establish duty cycle of a delivery vehicle.

3. Design Specifications
   - Establish a proposed DISC-FORD baseline engine design.

4. Detailed Design and Procurement

- Ricardo to carry out design, manufacturing and preliminary performance testing on initial DISC FORD engine.
- Ricardo to deliver detailed drawings in North American standards for Canadian manufacturers.
- Procure prototype and stock parts from manufacturers.
- Above work to occur in parallel with similar work statements carried out by Ricardo.

5. Engine Development

- To evaluate DISC-FORD prototype engine on dynamometer and make necessary modifications and/or recommendations.

6. In-Vehicle Testing

- Install Canadian prototype DISC engine into Purolator van and evaluate performance in vehicle.

7. Advanced Engine Concept

- Incorporate specified original equipment into a second prototype DISC-FORD engine, (e.g. crankshaft). Recommendations will be made based on test results.

8. Ignition/Injection Development

- Develop design options of a Canadian manufactured ignition/injection system for the DISC-FORD engine.

9. Alternative Combustion Chamber Designs

- Establish Canadian technology in the DISC-FORD head and combustion chamber design.
- Test, evaluate and make necessary recommendations comparing the original DISC head design against the new Canadian DISC head design.

10. DISC-Alcohol Engine

- Make necessary modifications to prototype DISC-FORD engine to accept alcohol fuels.
- Assemble and test baseline DISC-FORD alcohol engine on two grades of alcohol.

11. Fleet Testing and Demonstration

- Develop fleet test program followed up by a marketing and commercialization plan.
- Documentation for maintenance and troubleshooting.
- Final review meeting.

12. Management

- Continuous marketing studies, economic study and overall project management from start to completion of Phase II.

:sd

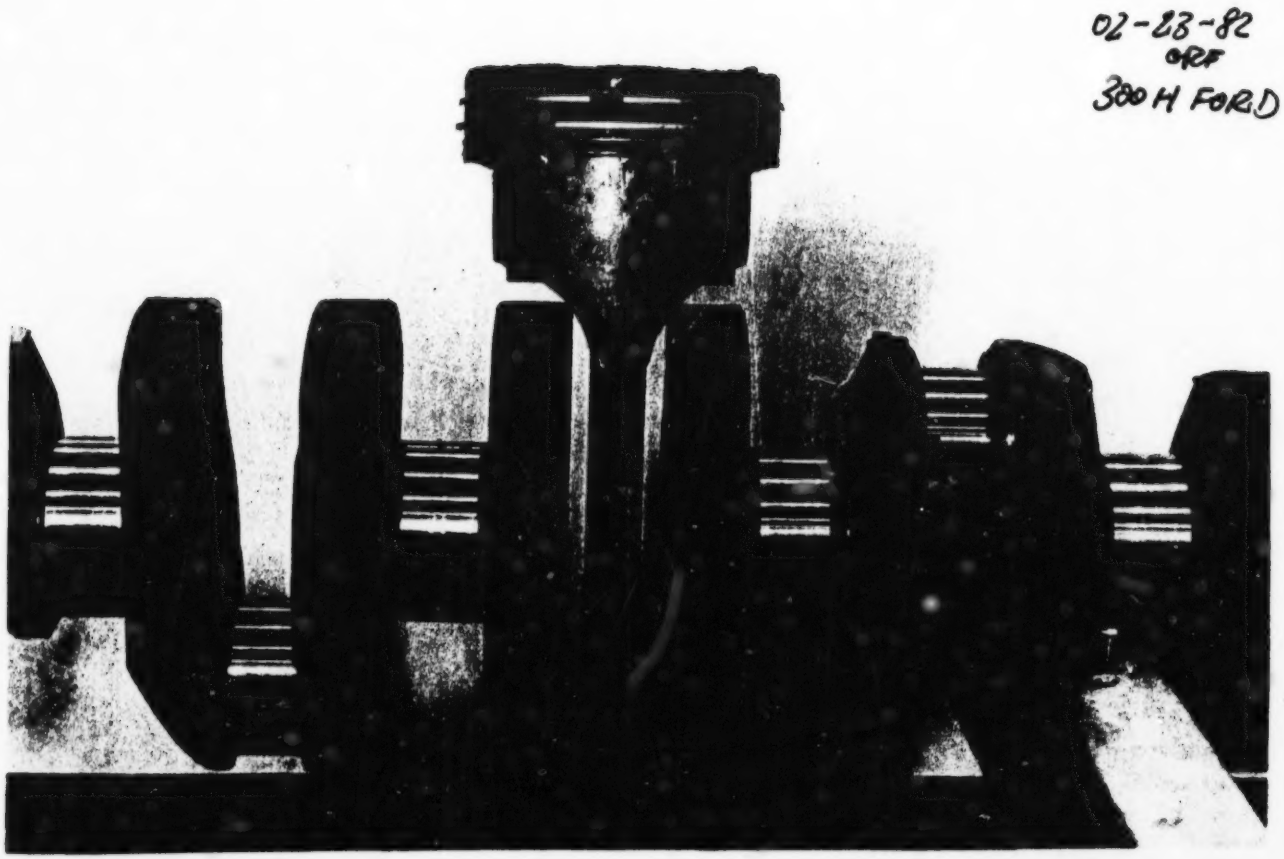

Figure 1: Crankshaft with Connecting Rod and Piston of Ford 300 H Engine

Feb 23/82
ORF
300H FORD

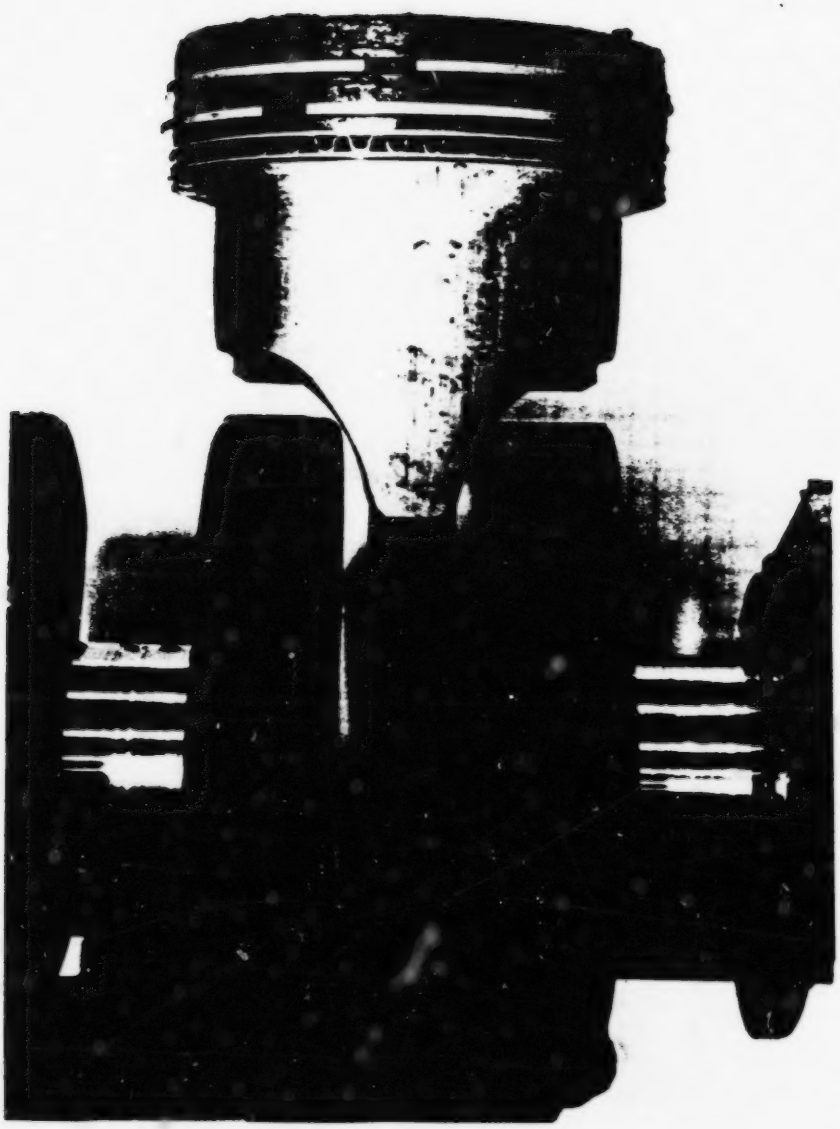

Figure 2: Close-up of Crankshaft with Connecting Rod and Piston of Ford 300 H Engine

STRATIFIED CHARGE PROJECT

COMPANY CONTACTED	:	Central Precision Ltd. (Rexdale)
PHONE NO.	:	(416) 745-5521
DATE	:	July 1982
CONTACT	:	H.T. Tyne (President) Marvin Thibault - Sales Mgr.
PARTS TO BE MANUFACTURED	:	completes manufactured engine heads
REFERENCES	:	Authorized Ford remanufacturer for Nisson, Ontario as well as International Harvester National Defense
LAST JOB	:	
WILL THE WORK BE DONE BY CANADIANS	:	Yes
ARE YOU PREPARED TO QUOTE A PRICE IN WRITING	:	Yes
OTHER COMMENTS	:	170 employees est. 1955

STRATIFIED CHARGE PROJECT

COMPANY CONTACTED	:	Accurate Crankshaft Grinding (Rexdale)
PHONE NO.	:	(416) 745-7754 Martin Grove Rd.
DATE	:	July 1982
CONTACT	:	Charles Tye (Gen. Mgr)
		Eddie Walsh (Foreman)
PARTS TO BE MANUFACTURED	:	crankshafts and cam shafts
REFERENCES	:	Canadian Tire
		Department of National Denfense
LAST JOB	:	Canadian Tire
WILL THE WORK BE DONE BY CANADIANS	:	Yes
ARE YOU PREPARED TO QUOTE A PRICE IN WRITING	:	Yes
OTHER COMMENTS	:	15 employees
		chrome plate valves

STRATIFIED CHARGE PROJECT

COMPANY CONTACTED	:	Zettel Mfg. Ltd. (Kitchener)
PHONE NO.	:	(519) 742-8389
DATE	:	July
CONTACT	:	Joe Zettel - President
PARTS TO BE MANUFACTURED	:	auto flywheels
REFERENCES	:	supplying all automotive industries
		10,000 flywheels/WEEK
LAST JOB	:	continuous
WILL THE WORK BE DONE BY CANADIANS	:	Yes
ARE YOU PREPARED TO QUOTE A PRICE IN WRITING	:	Yes
OTHER COMMENTS	:	- 90 employees
		- balancing flywheels should any work be necessary on the existing flywheel.

STRATIFIED CHARGE PROJECT

COMPANY CONTACTED	:	Action Metalizing & Machining (Toronto)
PHONE NO.	:	(416) 255-6848
DATE	:	July 14, 1982
CONTACT	:	Harry Timusks (owner)
PARTS TO BE MANUFACTURED	:	machine shop, piston rebuild
REFERENCES	:	Canadian Can Corp.
		Neilson Chocolate
		General Mills (L. Lewis)
		Atlas Steels
LAST JOB	:	Canadian Can
WILL THE WORK BE DONE BY CANADIANS	:	Yes
ARE YOU PREPARED TO QUOTE A PRICE IN WRITING	:	Yes
OTHER COMMENTS	:	- spray aluminum, bronze
		- babbit bearings by hand
		- metalize crankshaft
		- Heli arc welding
		- metalize aluminum
		- bore + hone cylinders

STRATIFIED CHARGE PROJECT

COMPANY CONTACTED	:	Eastern Rebuilders (Bedford, Quebec)
PHONE NO.	:	(514) 248-3334
DATE	:	July 14, 1982
CONTACT	:	Mr. Edward Luke - President
PARTS TO BE MANUFACTURED	:	engine parts manufacturing
REFERENCES	:	authorized Ford & Chrysler remanufacturer
		- crankshaft, cam shaft
		- heads
		- Armed Forces
LAST JOB	:	constantly
WILL THE WORK BE DONE BY CANADIANS	:	Yes
ARE YOU PREPARED TO QUOTE A PRICE IN WRITING	:	Yes
OTHER COMMENTS	:	Address: 106 Elizabeth Street
		Bedford, Quebec J0S 1B0
		- 72 employees

STRATIFIED CHARGE PROJECT

COMPANY CONTACTED	:	Robert Bosch (Detroit)
PHONE NO.	:	(313) 353-0575
DATE	:	July 14, 1982
CONTACT	:	Kurt Denneler
PARTS TO BE MANUFACTURED	:	injection and ignition systems
REFERENCES	:	continually doing their own R & D
LAST JOB	:	
WILL THE WORK BE DONE BY CANADIANS	:	No
ARE YOU PREPARED TO QUOTE A PRICE IN WRITING	:	Yes
OTHER COMMENTS	:	Full address - 26877 North Western Hwy. Southfield, Michigan 48034 contact is familiar with the Echlin/Stanadyne existence, however, is not knowledgeable about the technical details. Bosch may be one possible contender in the development of the required system, however, request a large advance notice.

STRATIFIED CHARGE PROJECT

COMPANY CONTACTED	:	Haley Ind. Ltd. (Haley, Ontario)
PHONE NO.	:	(613) 432-8841
DATE	:	July 13, 1982
CONTACT	:	Mr. Turnbull - President
PARTS TO BE MANUFACTURED	:	sand core casting
REFERENCES	:	All major engine manufacturers for aerospace Pratt and Whitney Rolls Royce (England)
LAST JOB	:	continuous
WILL THE WORK BE DONE BY CANADIANS	:	Yes
ARE YOU PREPARED TO QUOTE A PRICE IN WRITING	:	Yes
OTHER COMMENTS	:	highly recommended by Chrysler - Etobicoke Casting

STRATIFIED CHARGE PROJECT

COMPANY CONTACTED	:	Zollner Canada (Leamington)
PHONE NO.	:	(519) 326-2654
DATE	:	July 13, 1982
CONTACT	:	Richard Stockwell - Office Mgr. Ed Johnson - General Mgr.
PARTS TO BE MANUFACTURED	:	cast and machine pistons
REFERENCES	:	International Harvester Ford General Motors
LAST JOB	:	continuous
WILL THE WORK BE DONE BY CANADIANS	:	once in production
ARE YOU PREPARED TO QUOTE A PRICE IN WRITING	:	Yes
OTHER COMMENTS	:	- initial tooling layout of mold would be done in Fort Wayne, Indiania. - into heavy duty industry, but are available for other work presently. - engineering can work with designer to aid in quicker machining and easier machining.

STRATIFIED CHARGE PROJECT

COMPANY CONTACTED	:	Hardchrome Corp. of Canada (Toronto)
PHONE NO.	:	(416) 465-7561
DATE	:	July 13, 1982
CONTACT	:	Ed Romaniuk - President
PARTS TO BE MANUFACTURED	:	crankshafts
REFERENCES	:	Marsch Engineering - Port Colborne (834-3624)
		Stelco
LAST JOB	:	continuous
WILL THE WORK BE DONE BY CANADIANS	:	Yes
ARE YOU PREPARED TO QUOTE A PRICE IN WRITING	:	Yes
OTHER COMMENTS	:	generally deal with large crankshafts

STRATIFIED CHARGE PROJECT

COMPANY CONTACTED : Cyclo-Chrome Ind. Ltd. (Winnipeg)(now called Manitoba Bearing Ltd)

PHONE NO. : (204) 632-4292

DATE : July 13, 1982

CONTACT : Bill Artto

PARTS TO BE MANUFACTURED : grind crankshaft, chrome plating
6 cyl crank 30" long 4 stroke

REFERENCES : City of Winnipeg
Ryder Truck Rental (Winnipeg)
Henderson Power Corp.

LAST JOB :

WILL THE WORK BE DONE BY CANADIANS : Yes

ARE YOU PREPARED TO QUOTE A PRICE IN WRITING : Yes

OTHER COMMENTS :

STRATIFIED CHARGE PROJECT

COMPANY CONTACTED	:	Great Lakes Forgings Ltd. (Windsor)
PHONE NO.	:	(519) 945-1151
DATE	:	July 13, 1982
CONTACT	:	Alf Simone - Sales Manager
PARTS TO BE MANUFACTURED	:	conn. rods, (35-lb closed die forging)
REFERENCES	:	Ford
		Chrysler (prototype diesel for 1985)
		Deutz KHD (Canada/USA)
		American Chain/Cable
LAST JOB	:	continuous
WILL THE WORK BE DONE BY CANADIANS	:	Yes
ARE YOU PREPARED TO QUOTE A PRICE IN WRITING	:	Yes
OTHER COMMENTS	:	

STRATIFIED CHARGE PROJECT

COMPANY CONTACTED	:	Hastings Ltd. (Scarborough)
PHONE NO.	:	(416) 698-7161
DATE	:	July 13, 1982
CONTACT	:	Paul Jersake - VP. GM Brian Fox - Sales Engineer
PARTS TO BE MANUFACTURED	:	piston rings and filters
REFERENCES	:	General Motors (USA) 65 yrs est. Bombardier large after market
LAST JOB	:	constantly manufacturing
WILL THE WORK BE DONE BY CANADIANS	:	Yes process and manufacturing
ARE YOU PREPARED TO QUOTE A PRICE IN WRITING	:	Yes
OTHER COMMENTS	:	this company believes they are the only piston ring manufacturer in Canada at present

STRATIFIED CHARGE PROJECT

COMPANY CONTACTED	:	Dominion Forge (Windsor)
PHONE NO.	:	(519) 254-7545
DATE	:	July 13, 1982
CONTACT	:	Vince Adcar - Plant Research Mgr. Bernie Marks - President
PARTS TO BE MANUFACTURED	:	crankshafts, conn. rods, piston rings, cam shafts, almost any smaller components
REFERENCES	:	General Motors (piston rings) Chrysler (conn.rods) International H. (steering knuckles) Caterpillar (2-1b - 175-1b casting)
LAST JOB	:	constantly doing work
WILL THE WORK BE DONE BY CANADIANS	:	Yes
ARE YOU PREPARED TO QUOTE A PRICE IN WRITING	:	Yes
OTHER COMMENTS	:	2-175 1b castings potential

STRATIFIED CHARGE PROJECT

COMPANY CONTACTED	:	Kendon Mfg.Ltd. (Windsor)
PHONE NO.	:	(519) 966-1770
DATE	:	July 13, 1982
CONTACT	:	Don Bryan (President)
PARTS TO BE MANUFACTURED	:	rocker arm assembly (machin.), oil pumps, exhaust manifolds.
REFERENCES	:	Caterpillar Cummins John Deere
LAST JOB	:	preproduction and prototype going on constantly
WILL THE WORK BE DONE BY CANADIANS	:	Yes
ARE YOU PREPARED TO QUOTE A PRICE IN WRITING	:	Yes
OTHER COMMENTS	:	- print to product - manufact.

STRATIFIED CHARGE PROJECT

COMPANY CONTACTED	:	A.G. Anderson (London, Ontario)
PHONE NO.	:	(519) 455-5420
DATE	:	July 13, 1982
CONTACT	:	Mr. Scott
PARTS TO BE MANUFACTURED	:	anything - 1b -> 1000 1b casting
REFERENCES	:	Michelin Tire (La Salle) Excello Rockwell International Cannon, Kelsey Hayes
LAST JOB	:	constantly manufacturing
WILL THE WORK BE DONE BY CANADIANS	:	Yes
ARE YOU PREPARED TO QUOTE A PRICE IN WRITING	:	Yes
OTHER COMMENTS	:	"Cadcam" system computerated design and machining. - 65 employees

POOR

QUALITY

ORIGINAL